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Yoneda et al.

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(54) **ELECTRONIC COMPONENT**

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H01F 27/26 (2006.01)
H01F 27/28 (2006.01)
H01F 17/00 (2006.01)

(52) **U.S. Cl.**

CPC ***H01F 27/2804*** (2013.01); ***H01F 17/0013*** (2013.01); *H01F 2017/002* (2013.01)

(58) **Field of Classification Search**

CPC H01F 5/00; H01F 27/28
USPC 336/200, 232
See application file for complete search history.

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An Office Action; "Notification of Reasons for Rejection," issued by the Japanese Patent Office on Feb. 24, 2015, which corresponds to Japanese Patent Application No. 2013-083048 and is related to U.S. Appl. No. 14/203,497; with English language translation.

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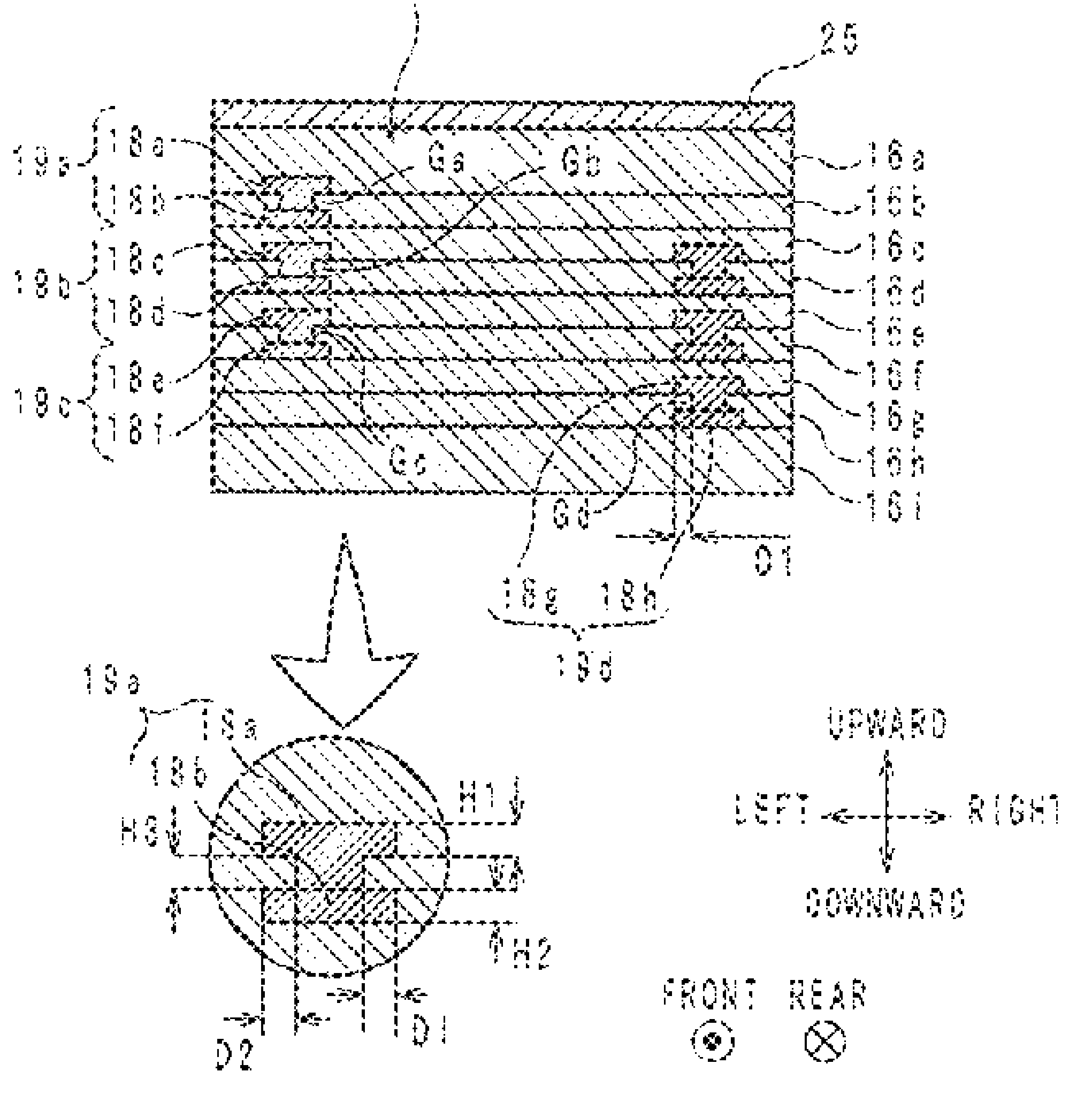
(74) *Attorney, Agent, or Firm* — Studebaker & Brackett PC

(57) ABSTRACT

An electronic component having: a laminate formed by laminating a plurality of insulator layers; and a coil consisting of linear coil conductor layers that are laminated along with the insulator layers, the coil having a spiral form or a helical form that windingly extends in a direction of lamination. In a cross section perpendicular to a direction in which the coil conductor layers extend, the coil conductor layers have recesses provided in their surfaces directed toward an inner circumference side of the coil, the recesses being set back toward an outer circumference side of the coil.

9 Claims, 15 Drawing Sheets



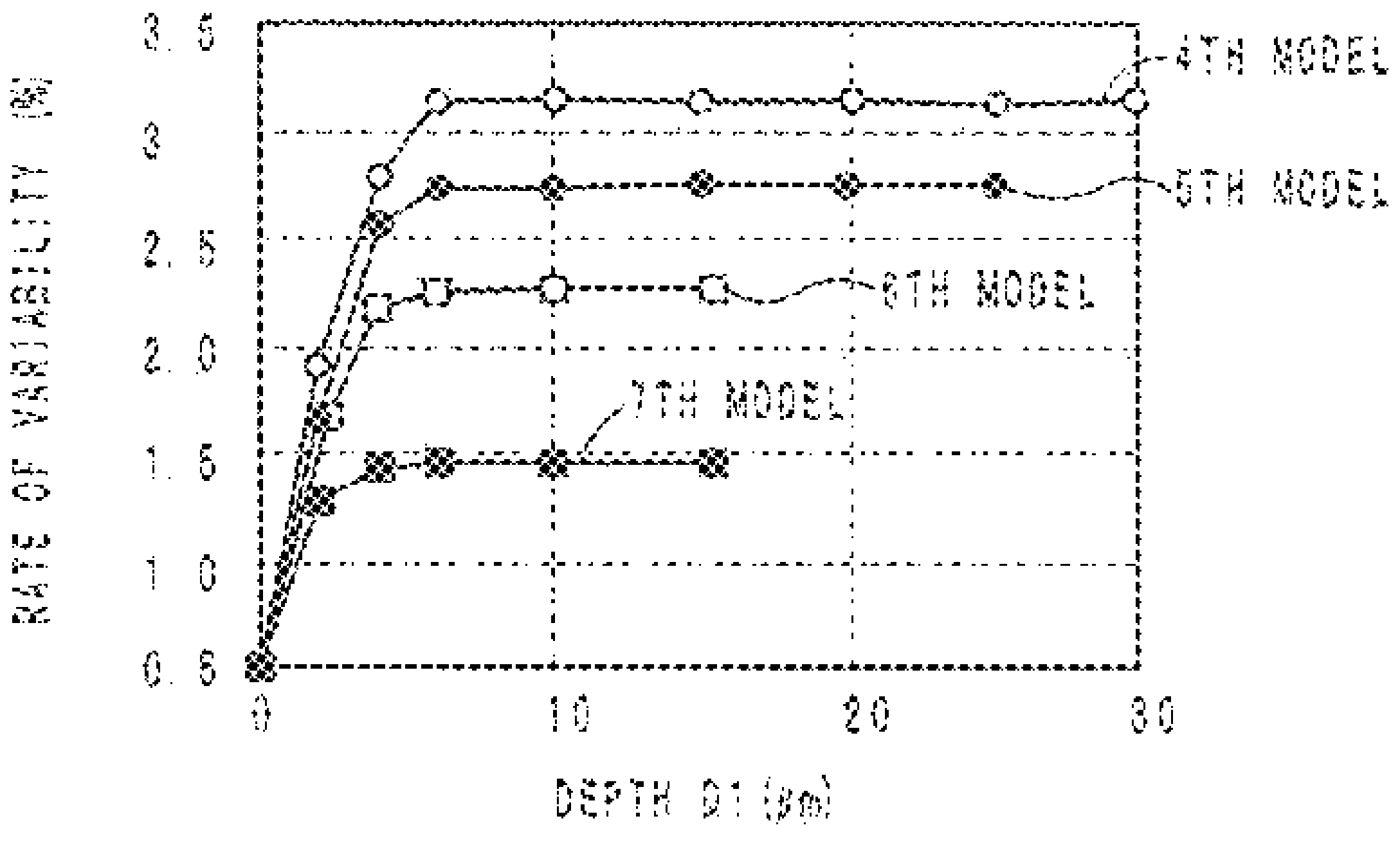


FIG. 1

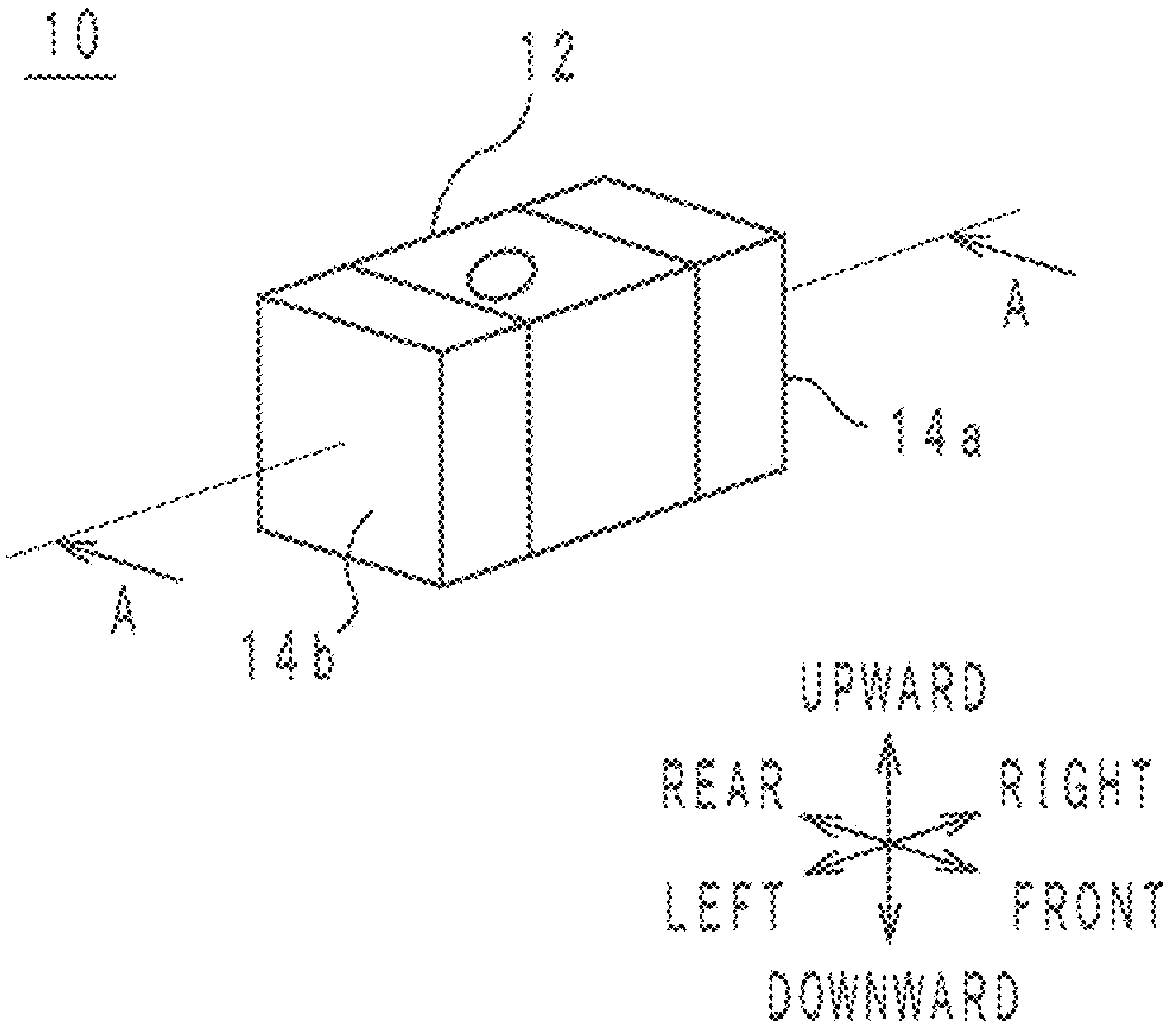


FIG. 2

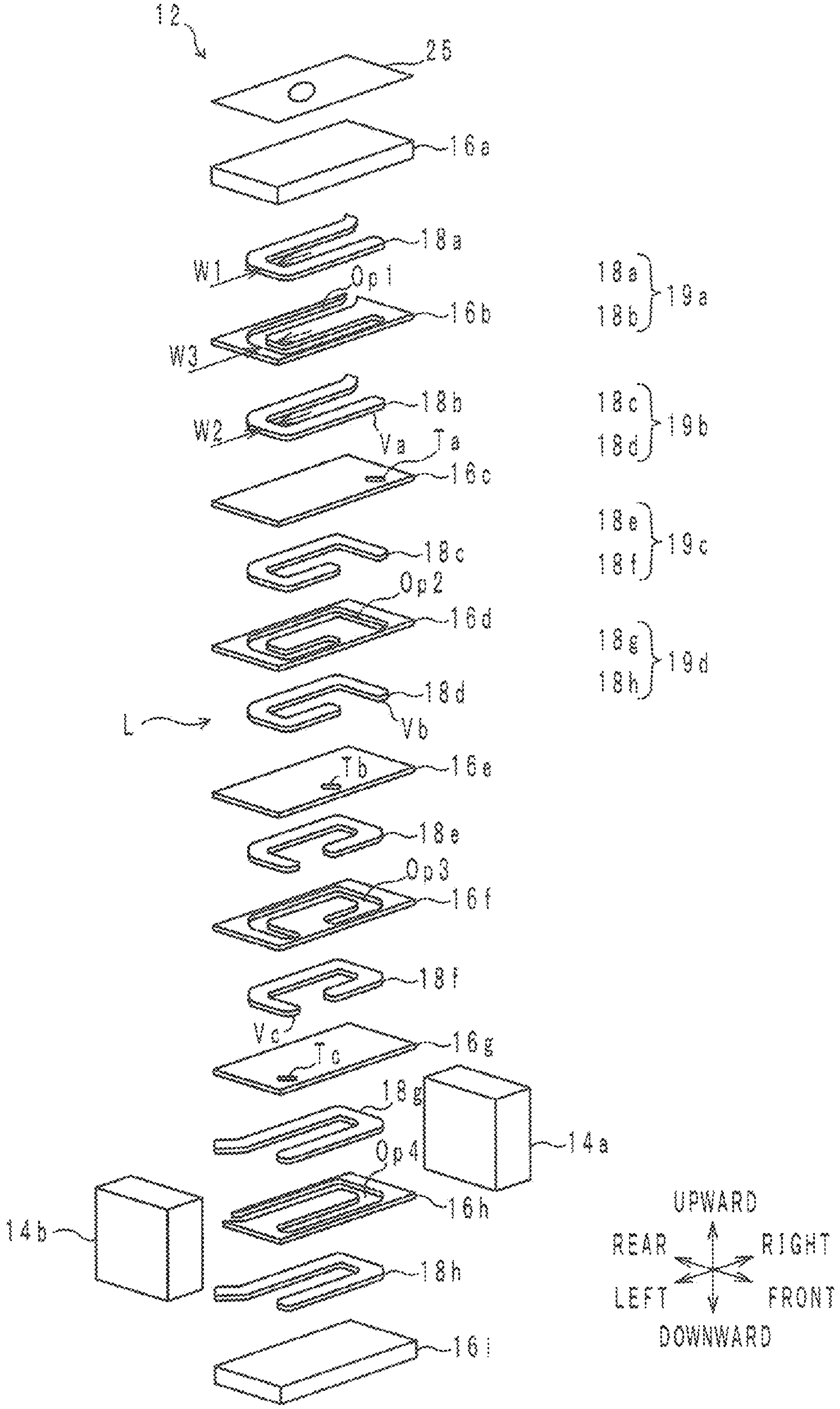

12
25
16a
18a
W1
Op1
16b
W3
18b
W2
Va
Ta
16c
18c
Op2
16d
18d
Vb
L
16e
Tb
18e
Op3
16f
18f
Vc
16g
Tc
18g
14a
Op4
16h
14b
18h
16i
18a
18b
19a
18c
18d
19b
18e
18f
19c
18g
18h
19d
UPWARD
REAR
RIGHT
LEFT
FRONT
DOWNWARD

FIG. 3

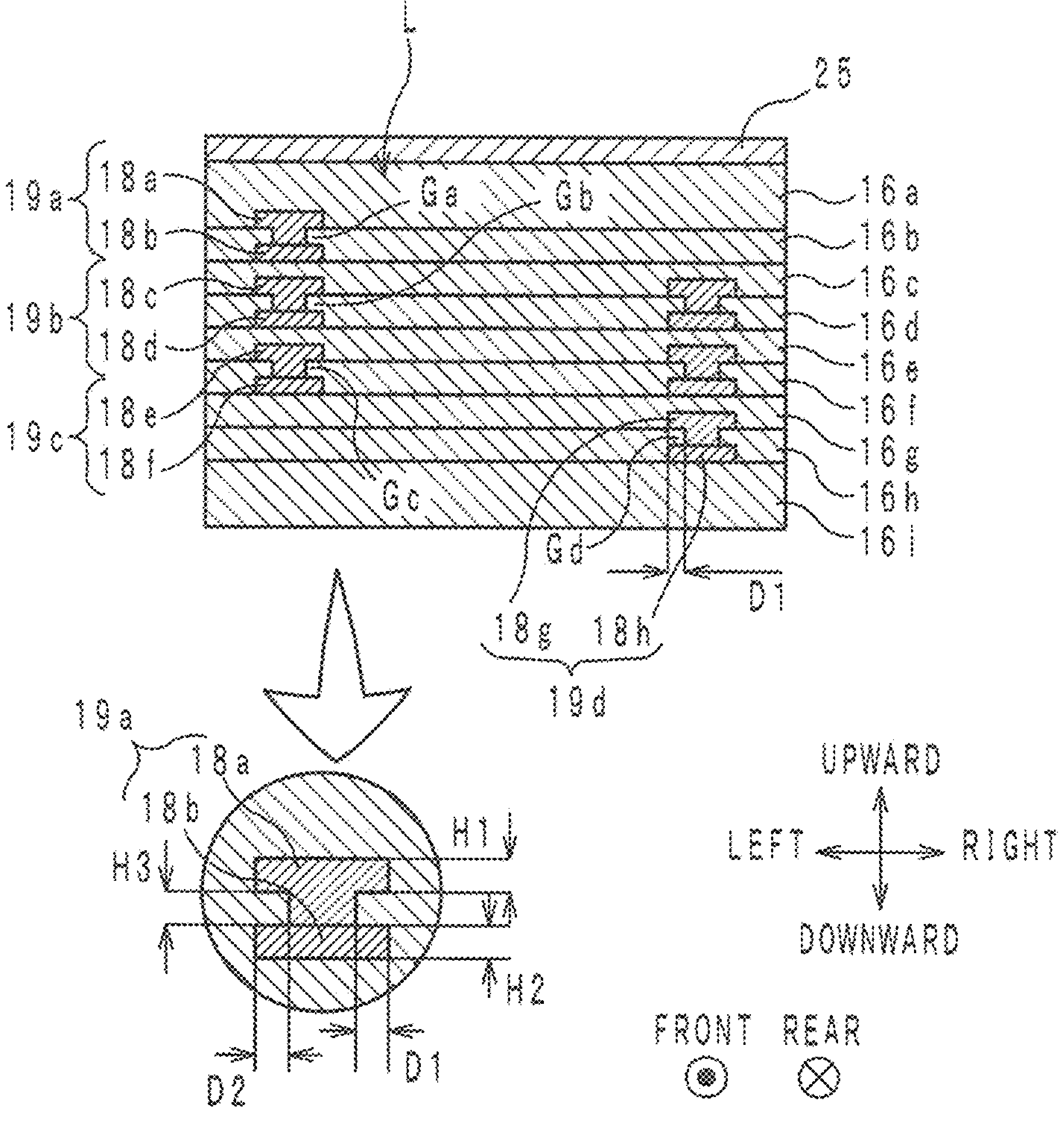

L
25
19a
18a
18b
Ga
Gb
19b
18c
18d
19c
18e
18f
Gc
16a
16b
16c
16d
16e
16f
16g
16h
16i
Gd
D1
18g
18h
19d
19a
18a
18b
H1
H3
H2
D2
D1
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 4

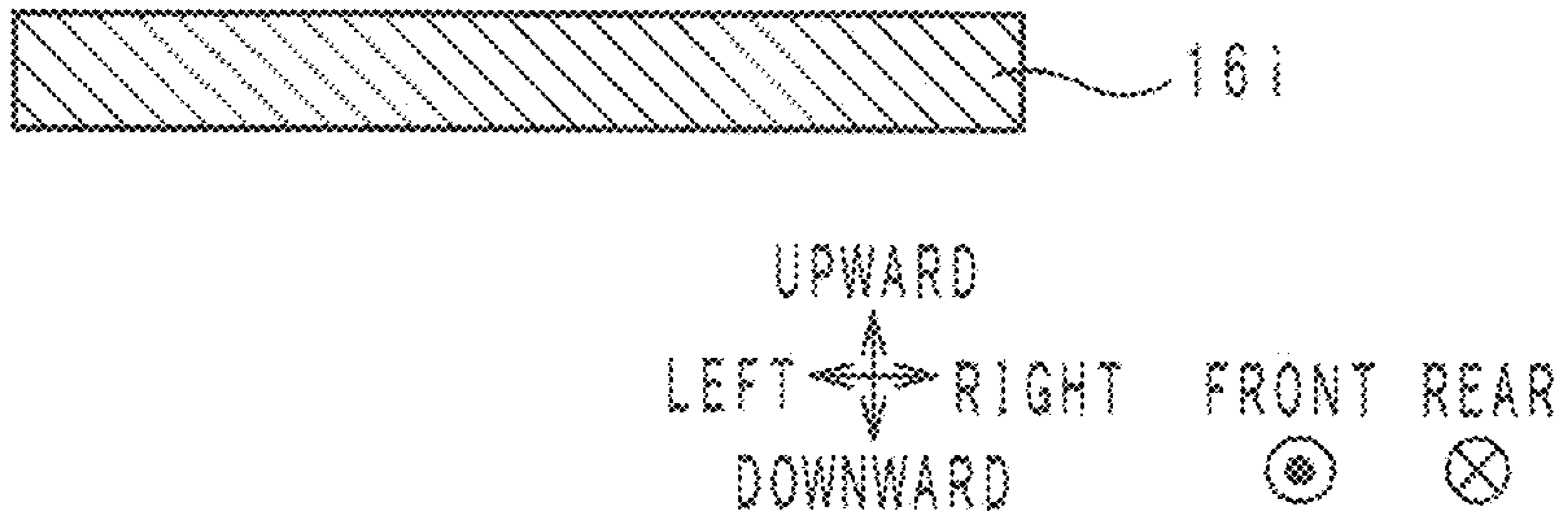
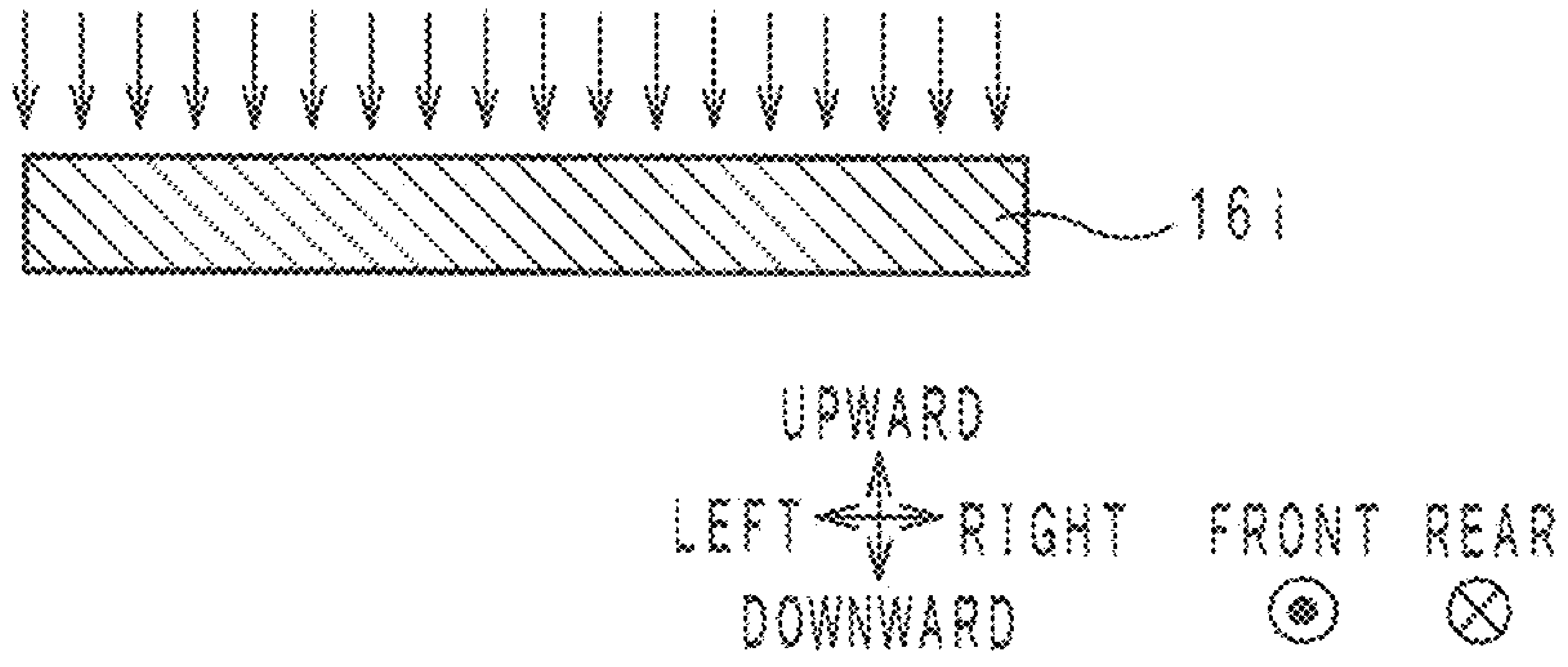
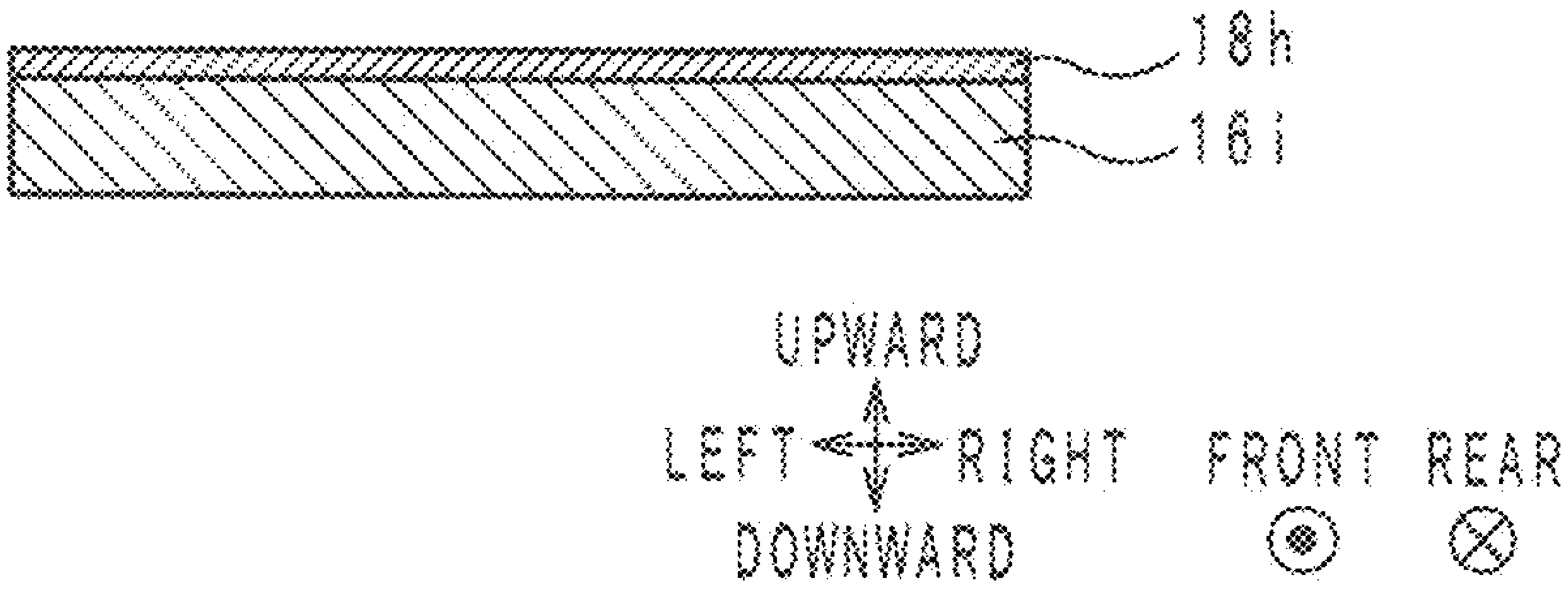

16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

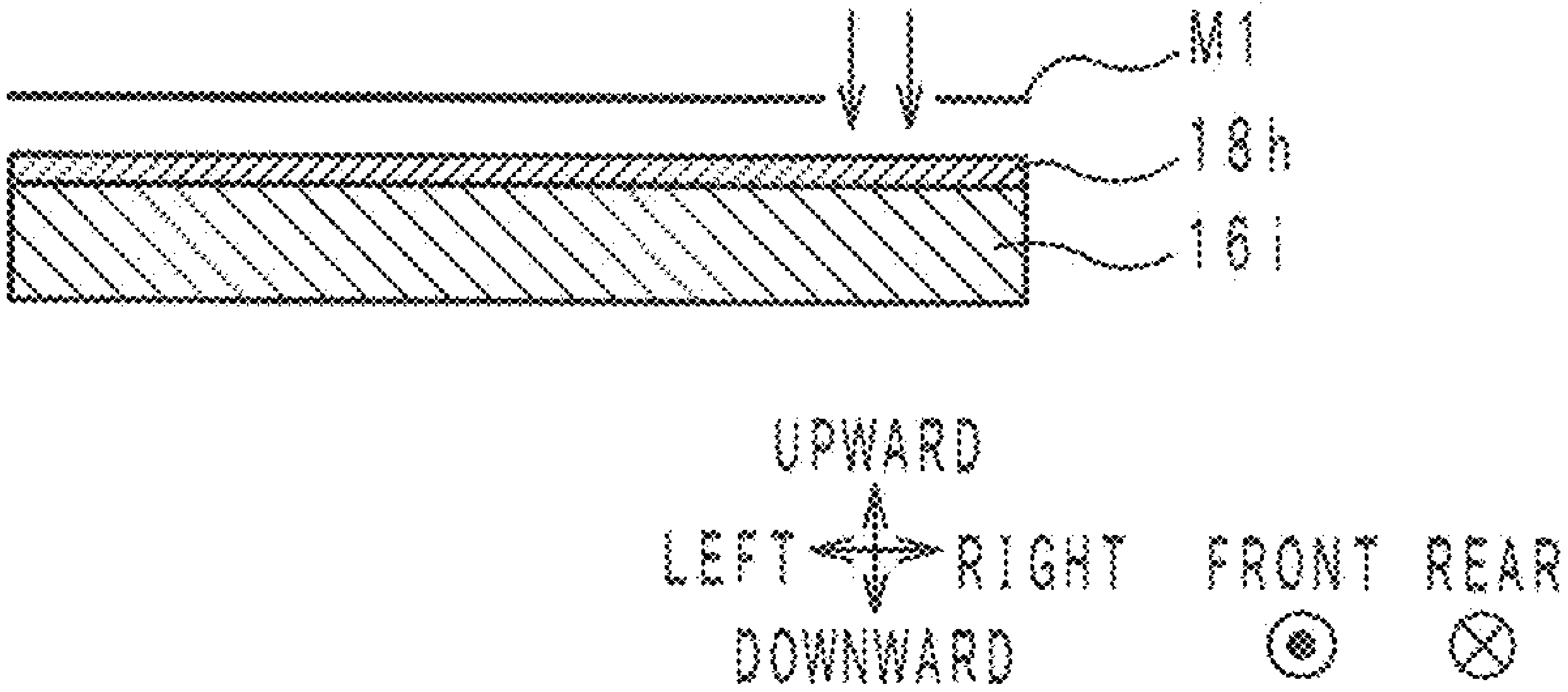
FIG. 5


16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

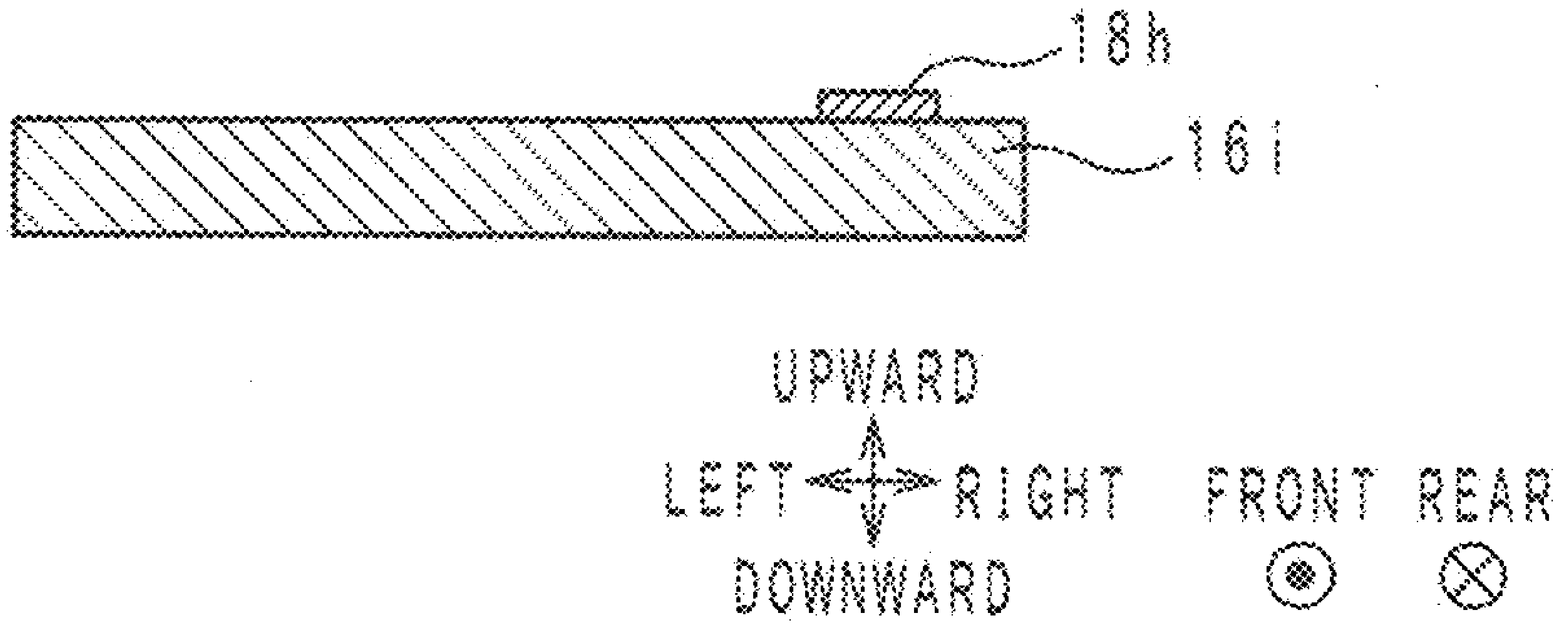
F I G. 6


18h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

F I G. 7


M1
18h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

F I G. 8


18h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

F I G. 9

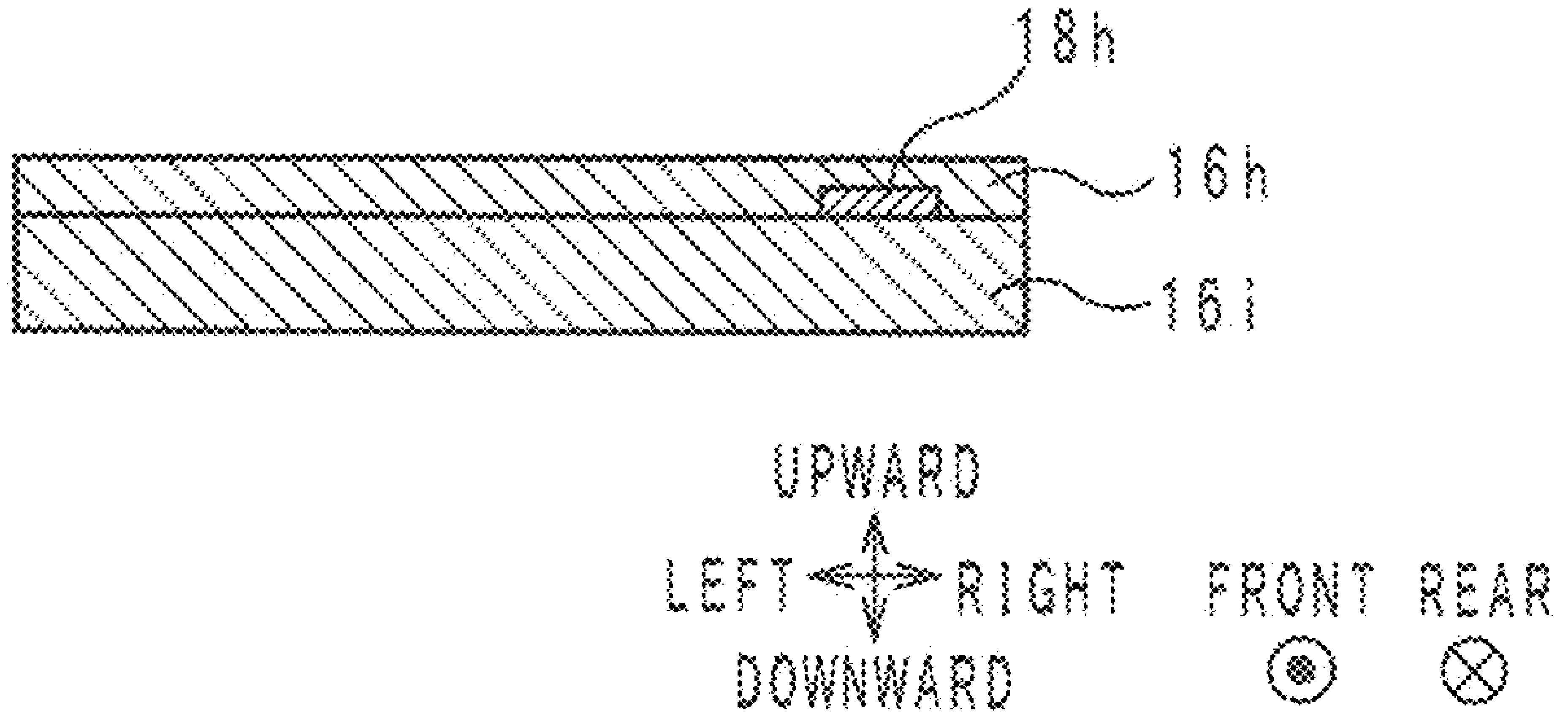

18h
16h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 10

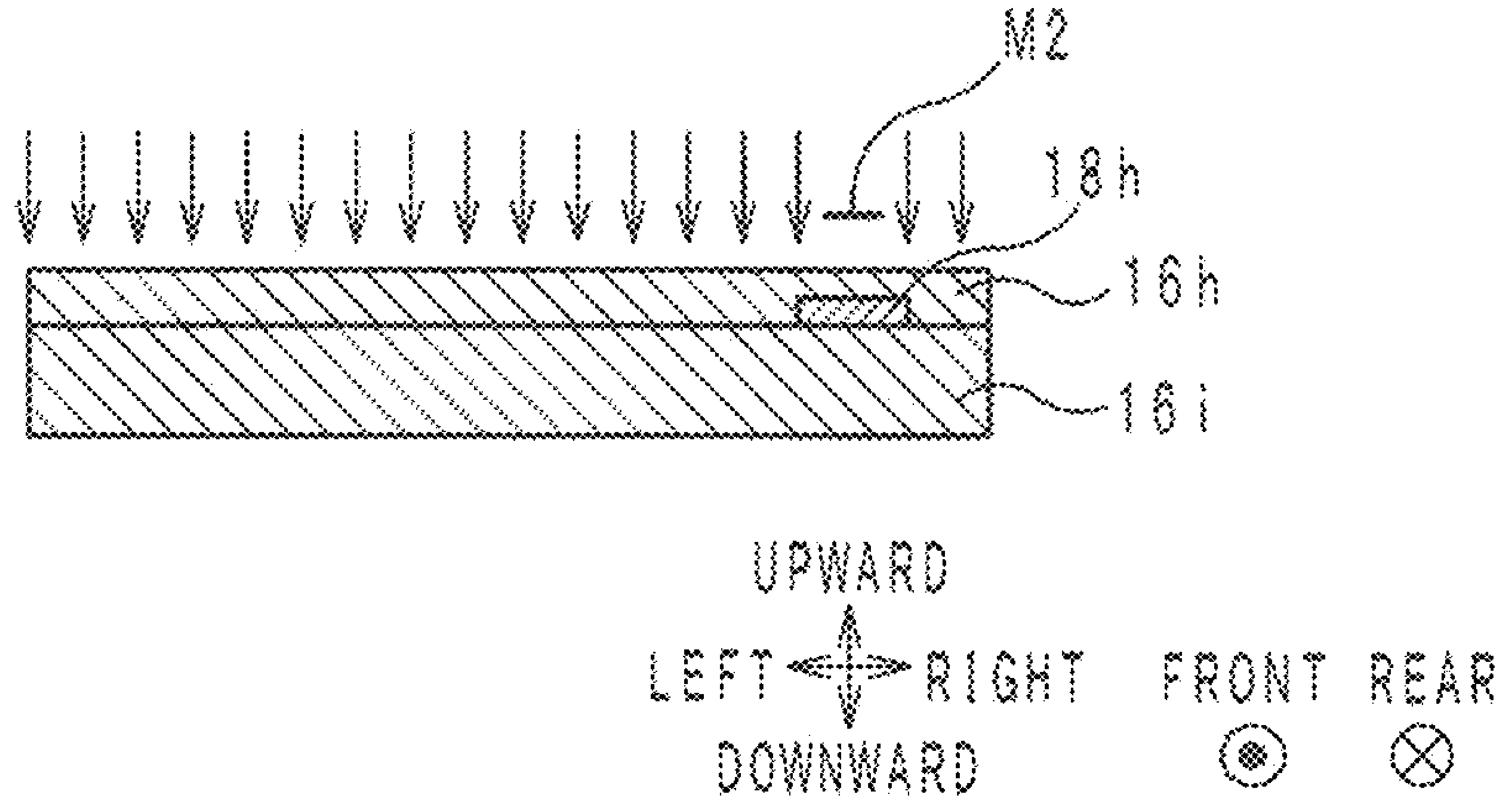

M2
18h
16h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 11

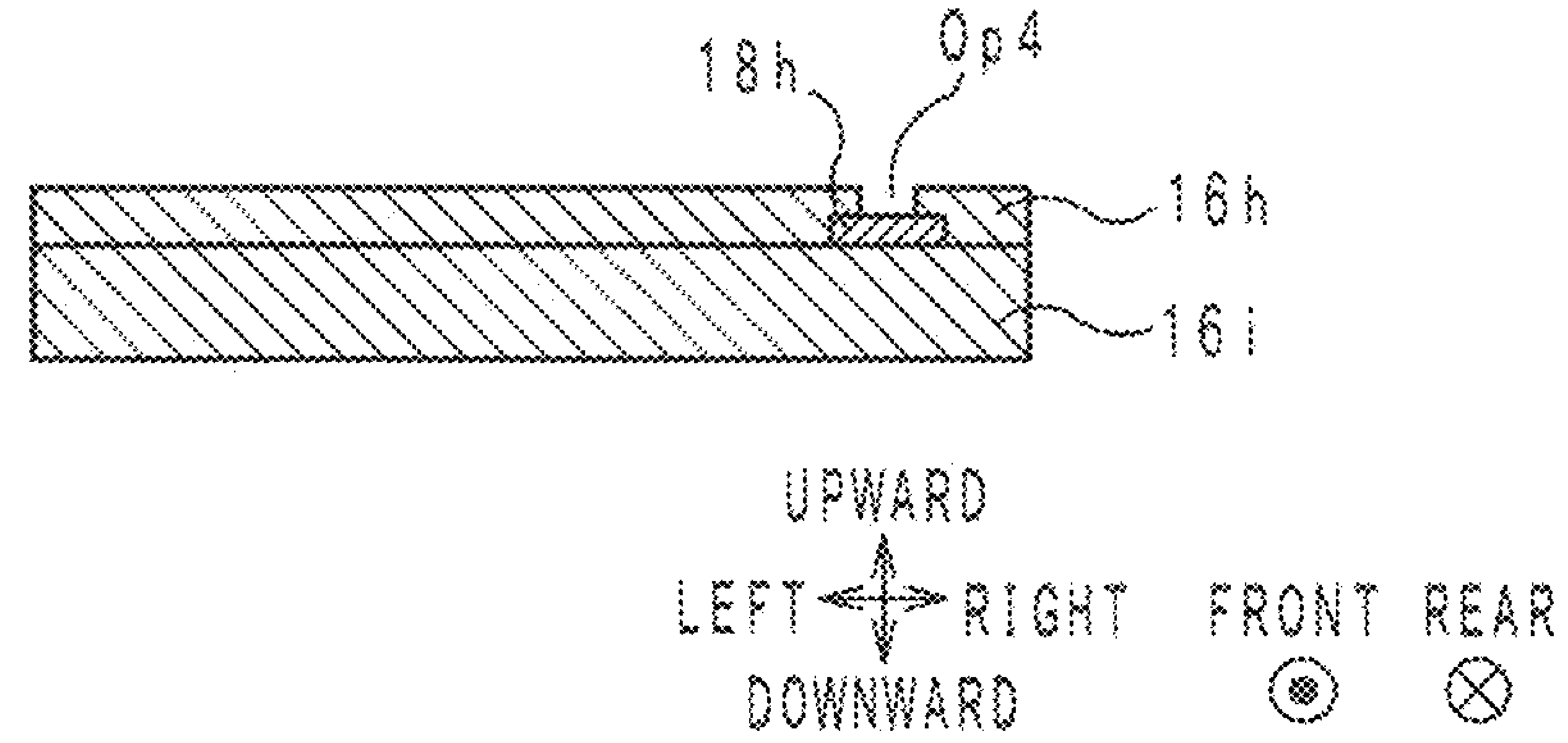

18h
Op4
16h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 12

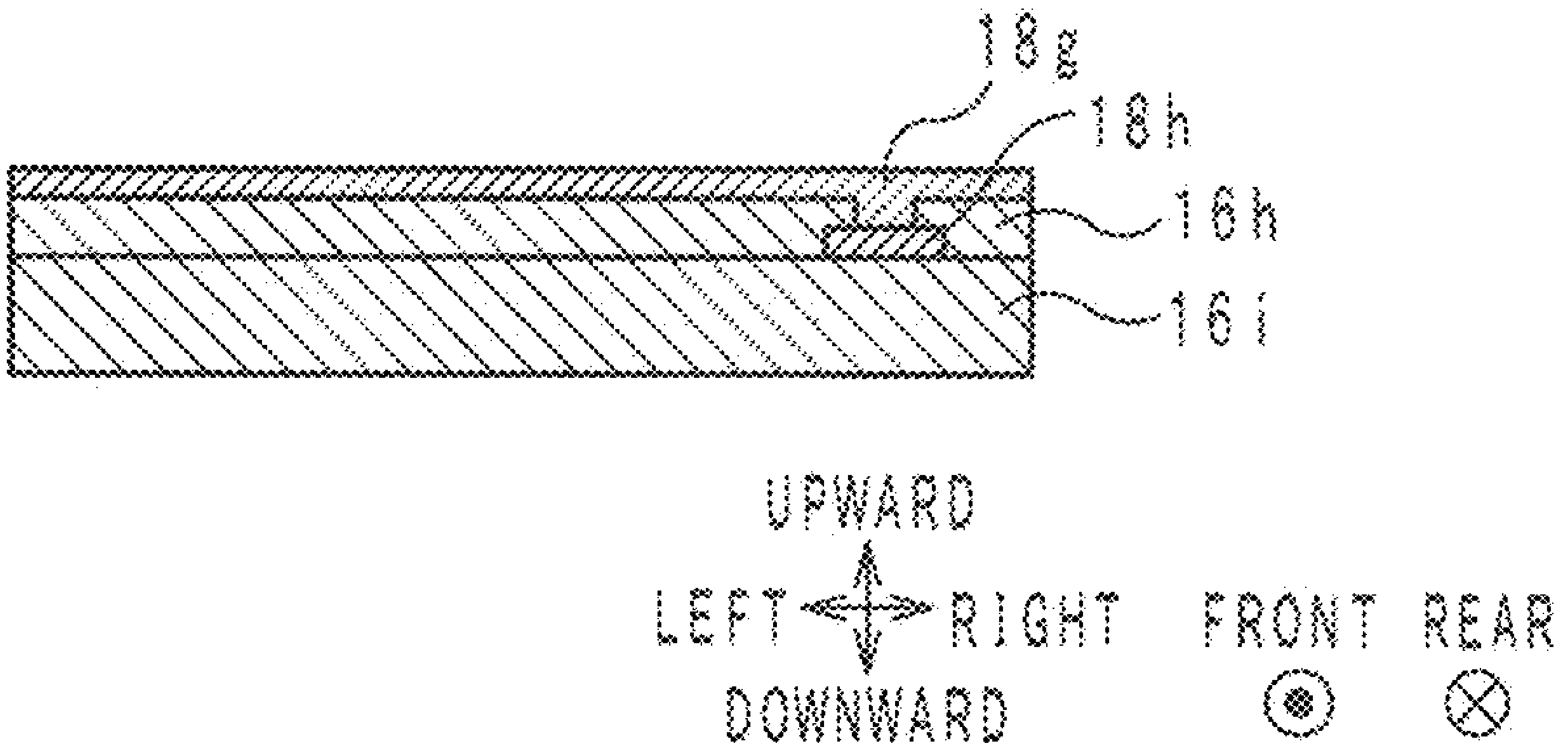

18g
18h
16h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 13

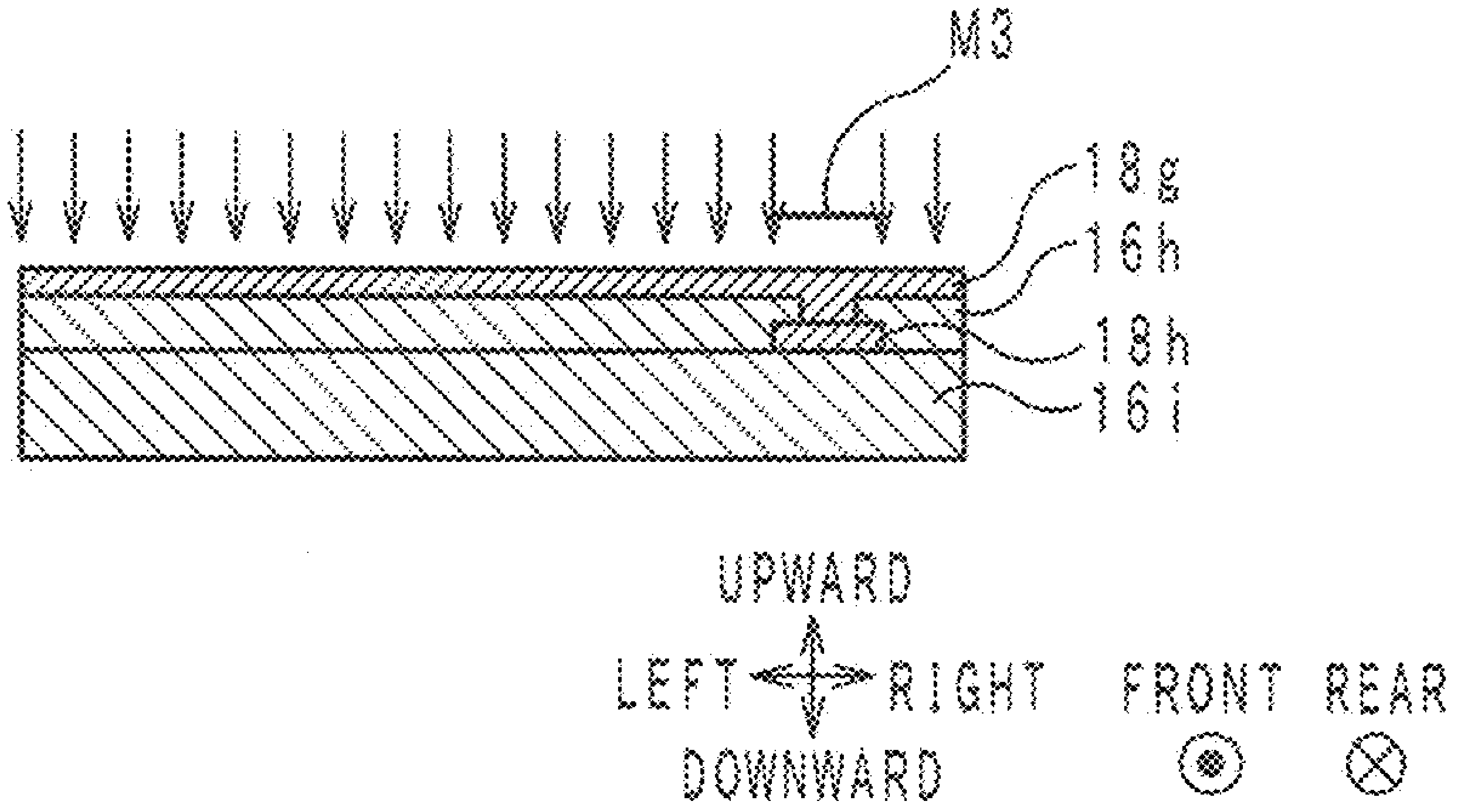

M3
18g
16h
18h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 14

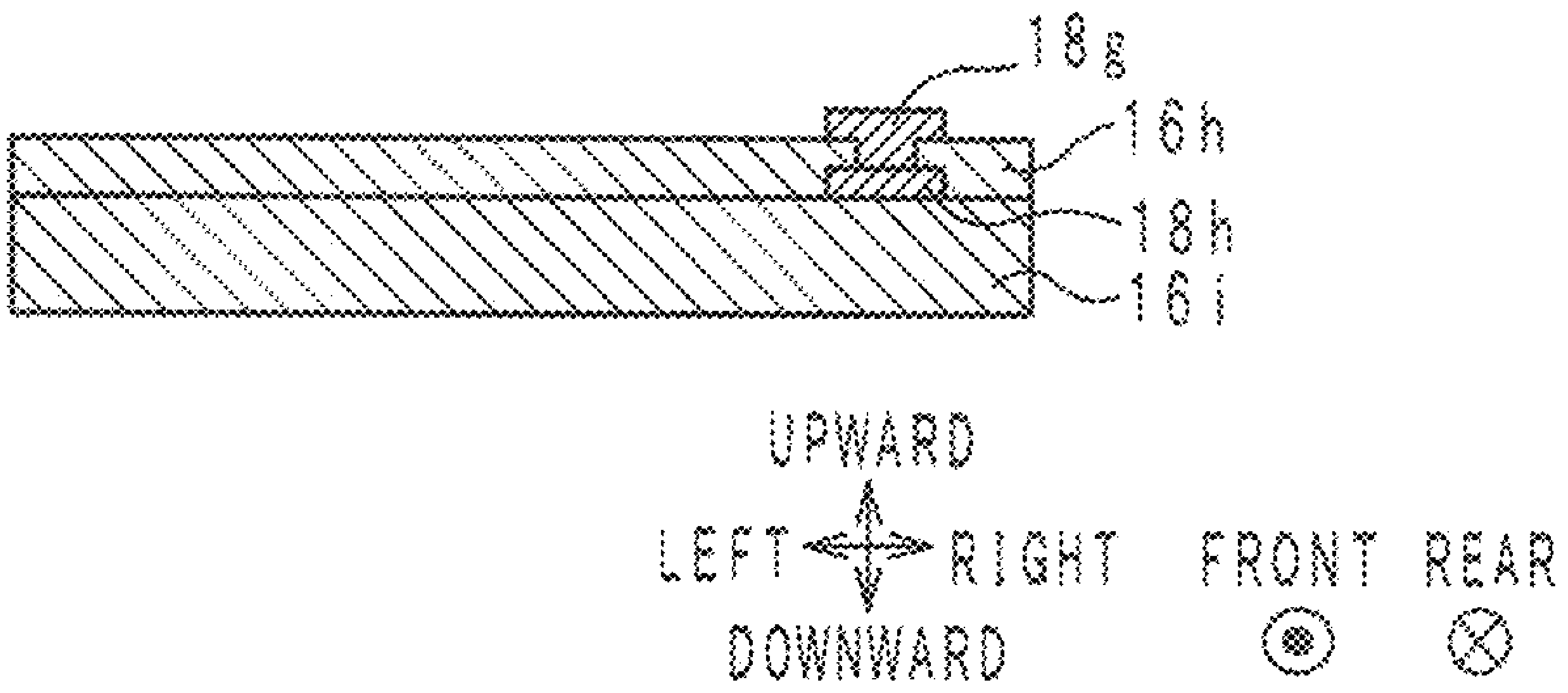

18g
16h
18h
16i
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 15

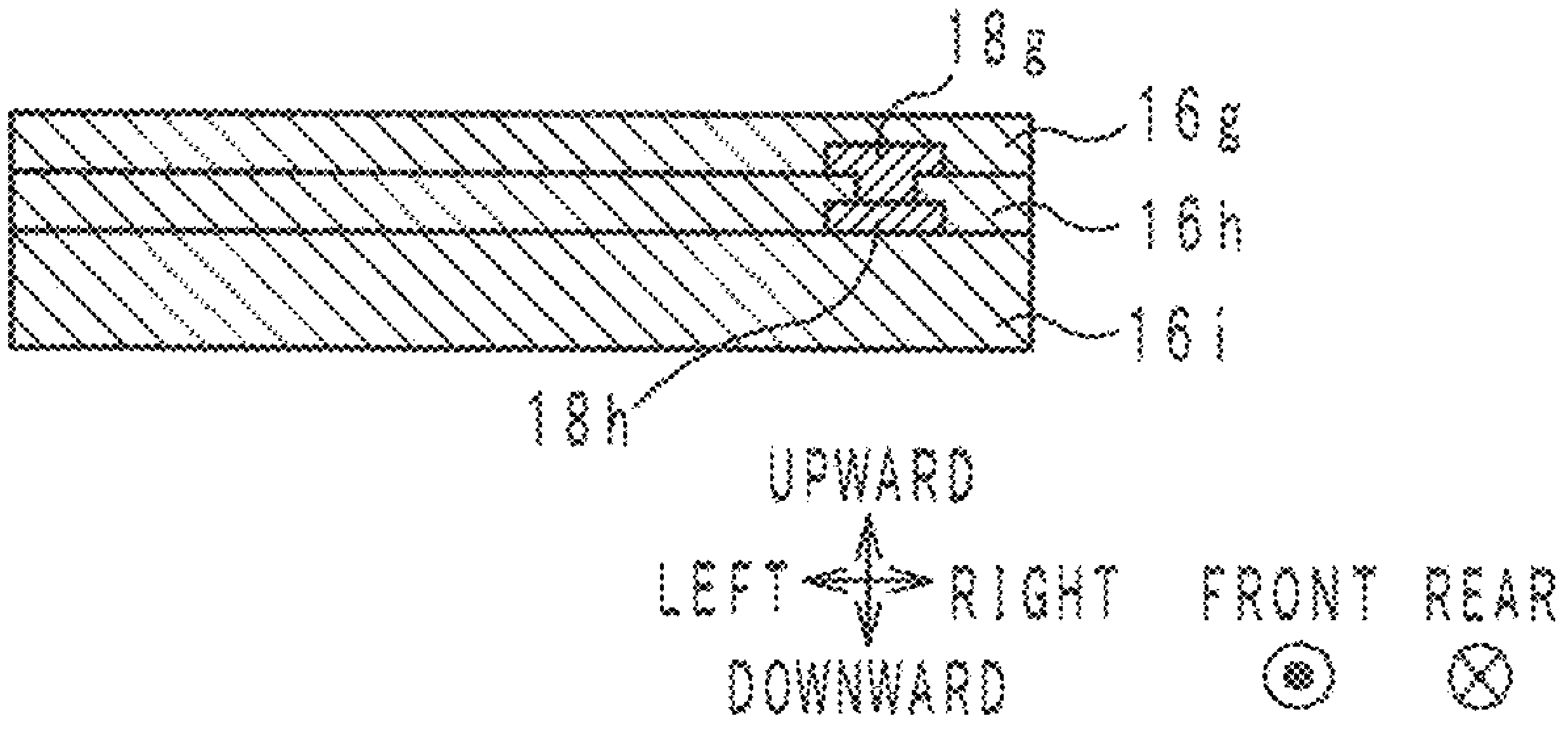

18g
16g
16h
16i
18h
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 16

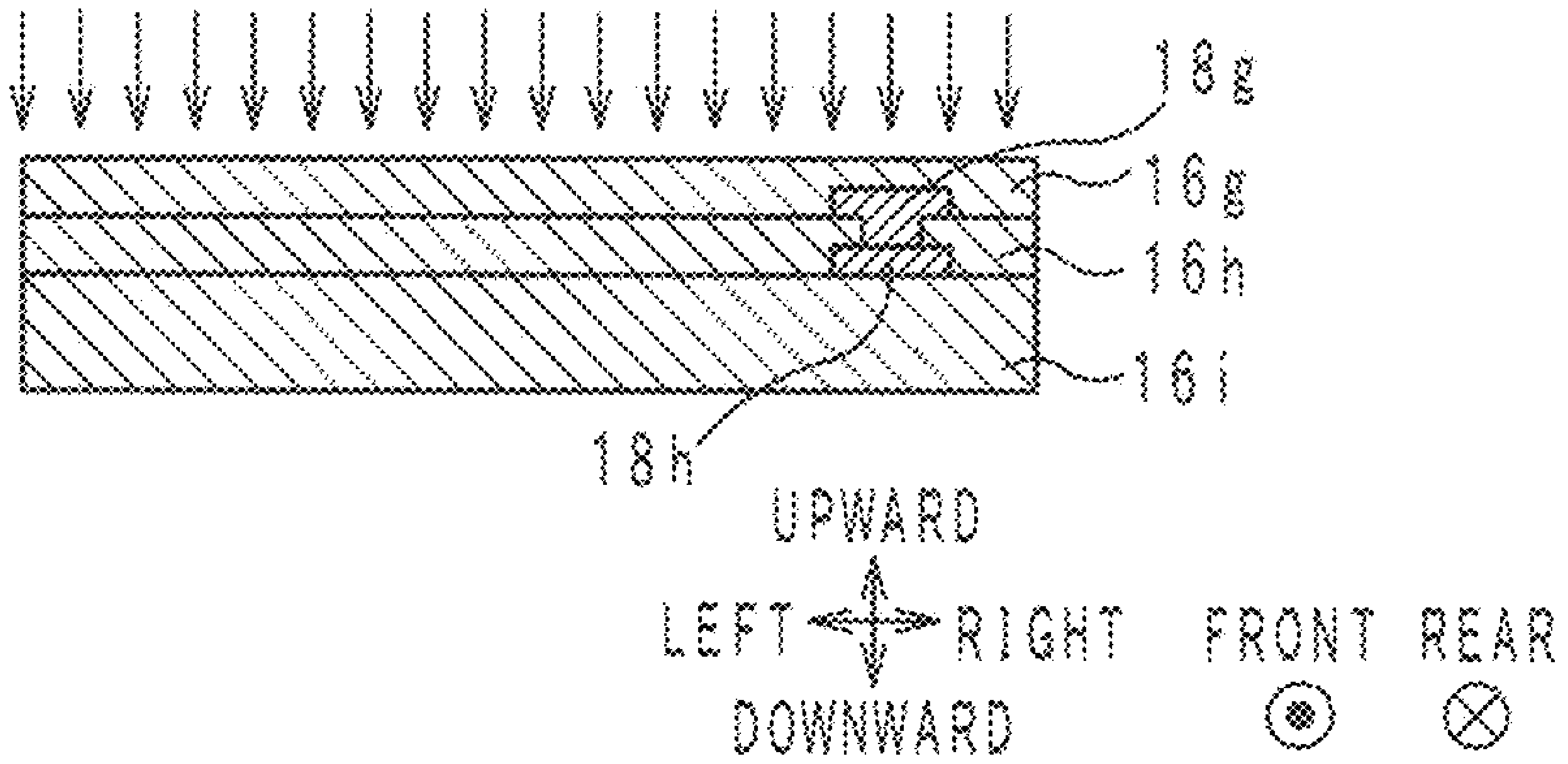

18g
16g
16h
16i
18h
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 17

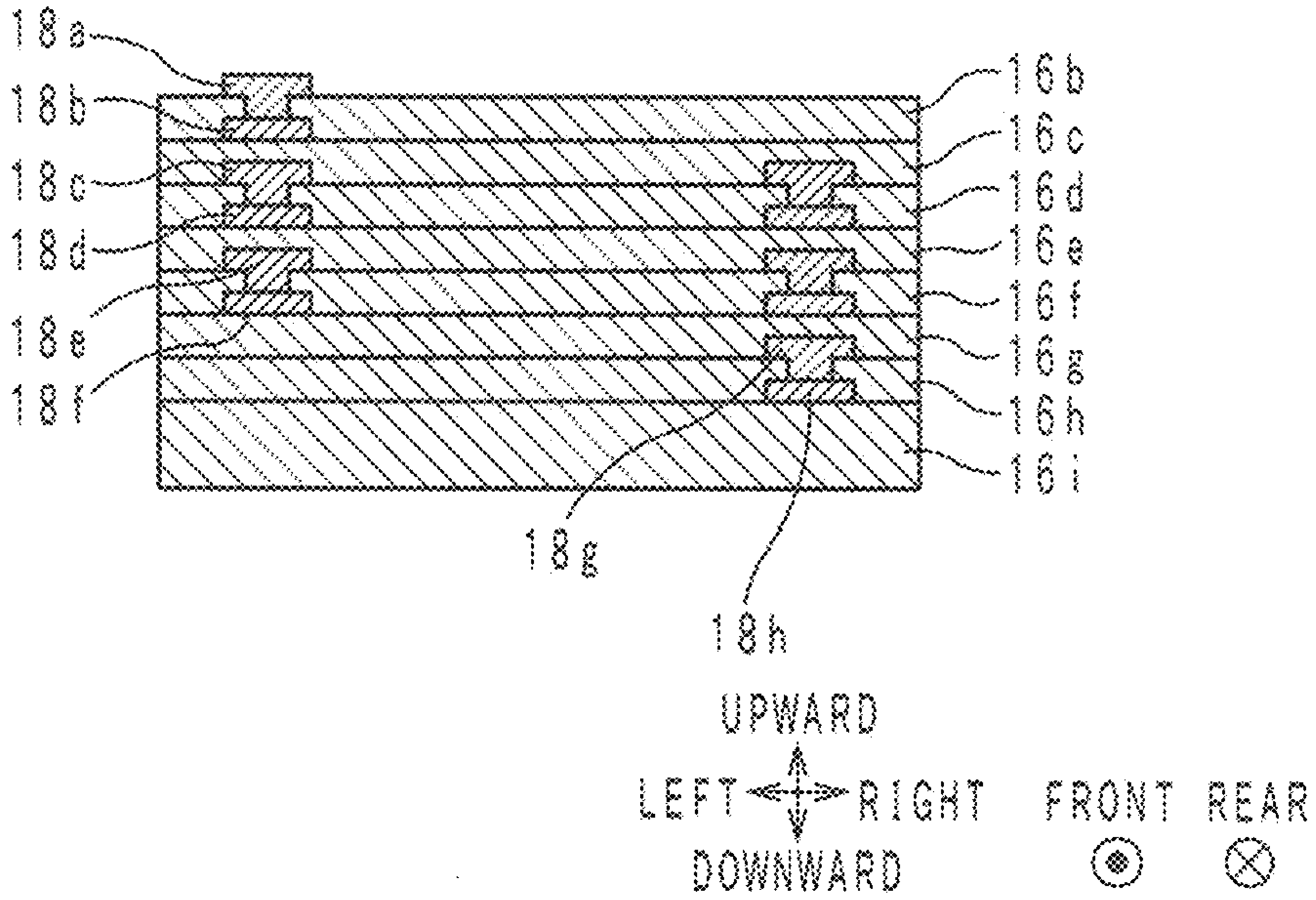

18a
18b
18c
18d
18e
18f
16b
16c
16d
16e
16f
16g
16h
16i
18g
18h
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 18

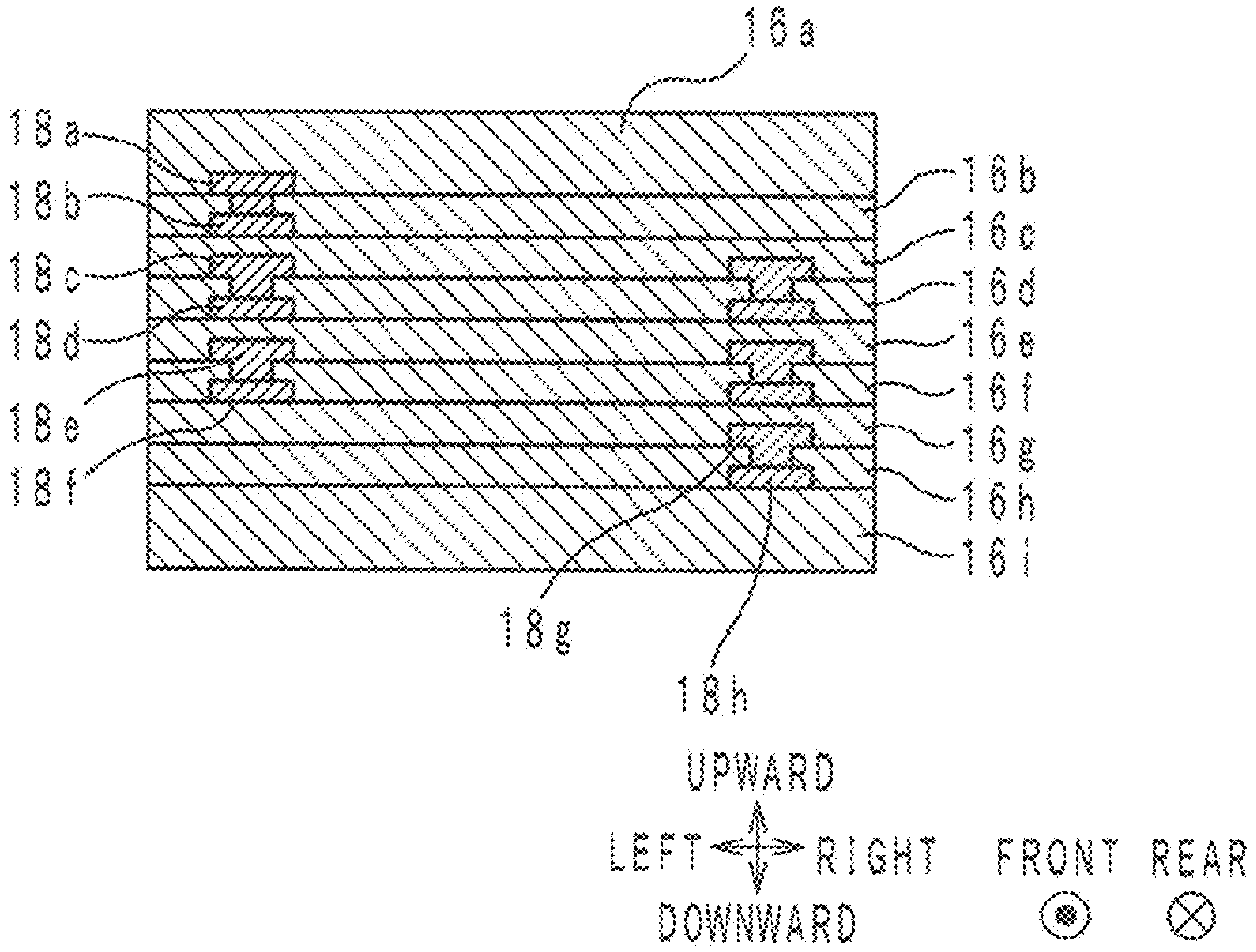

16a
18a
18b
18c
18d
18e
18f
16b
16c
16d
16e
16f
16g
16h
16i
18g
18h
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 19

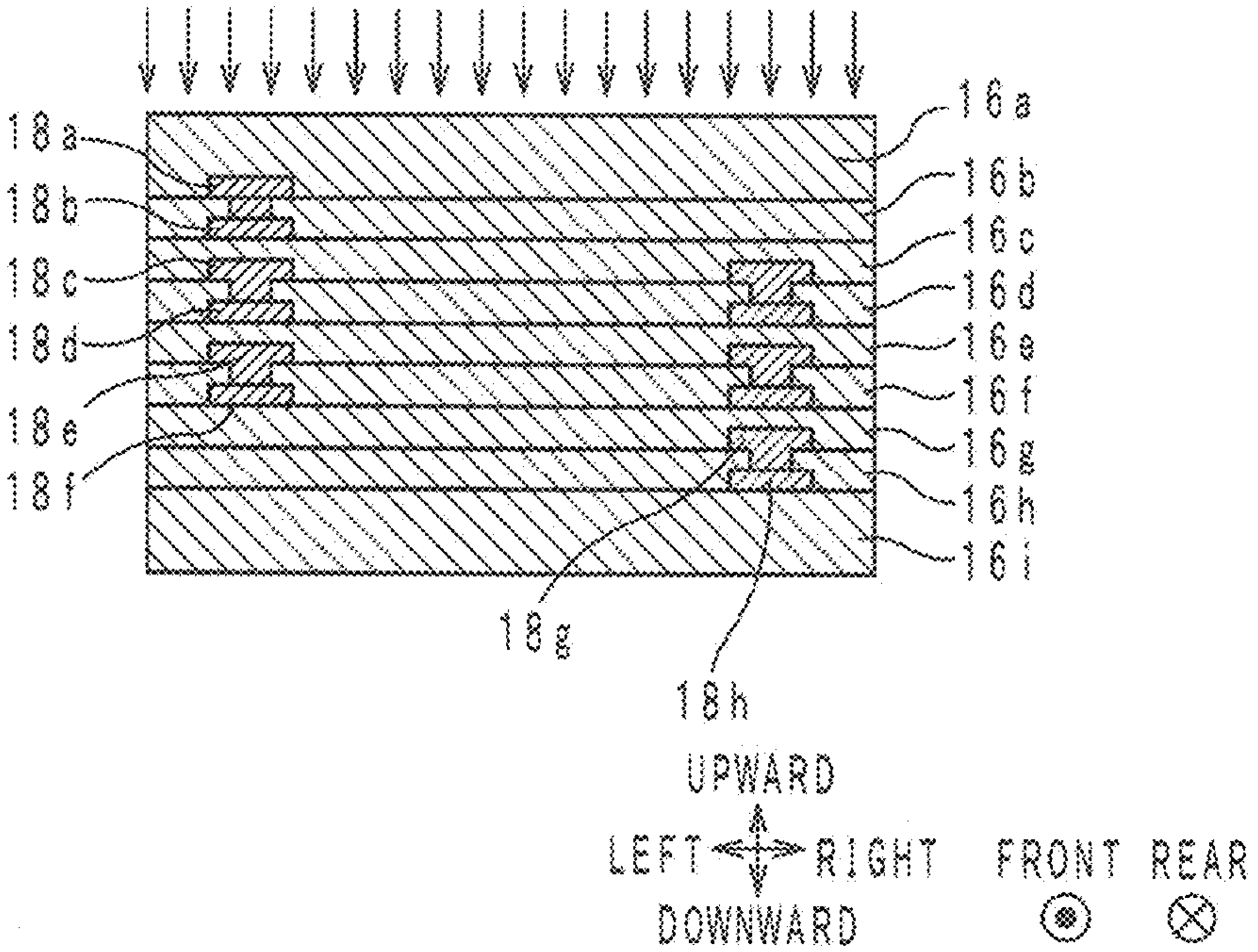

18a
18b
18c
18d
18e
18f
16a
16b
16c
16d
16e
16f
16g
16h
16i
18g
18h
UPWARD
LEFT
RIGHT
DOWNWARD
FRONT
REAR

FIG. 20

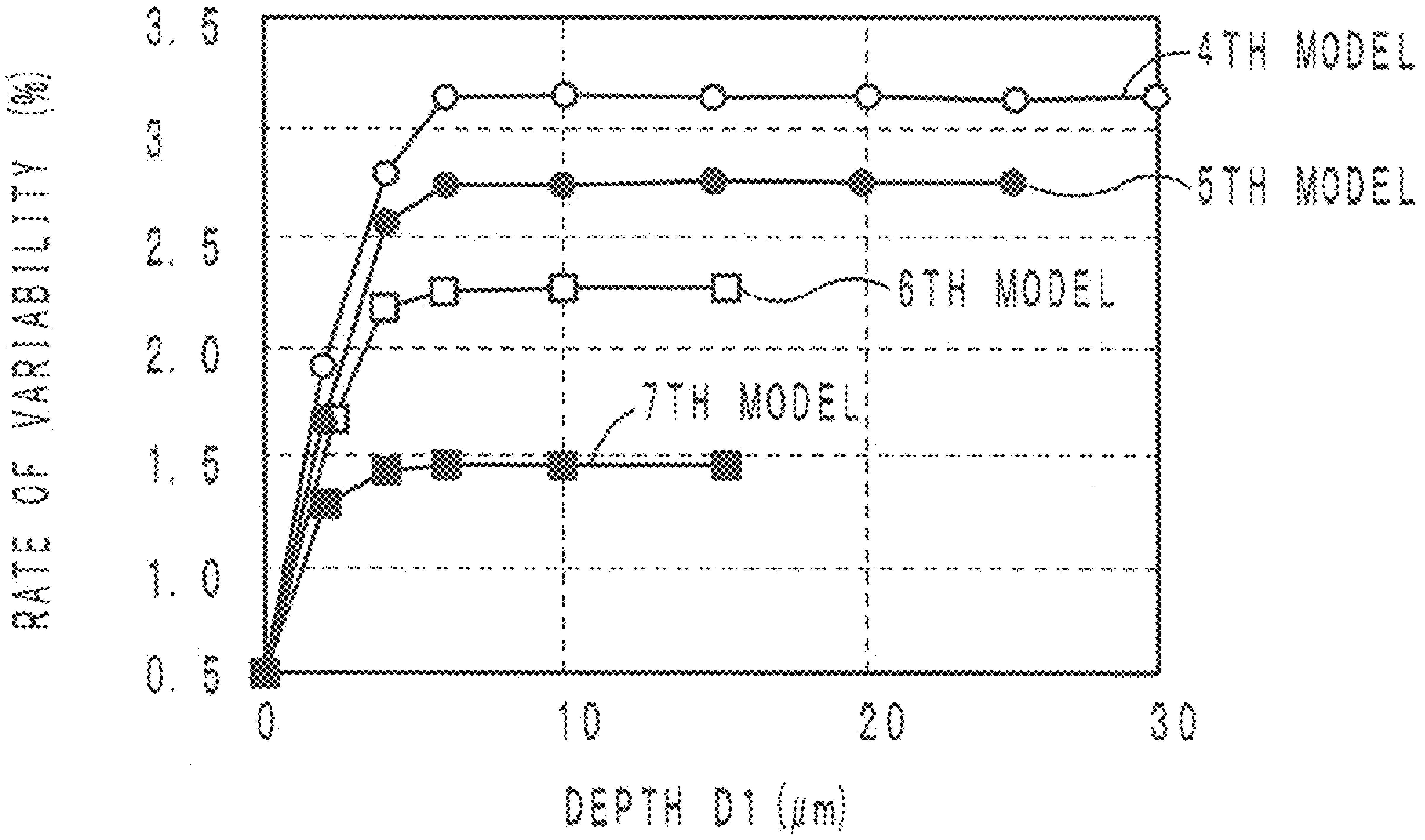
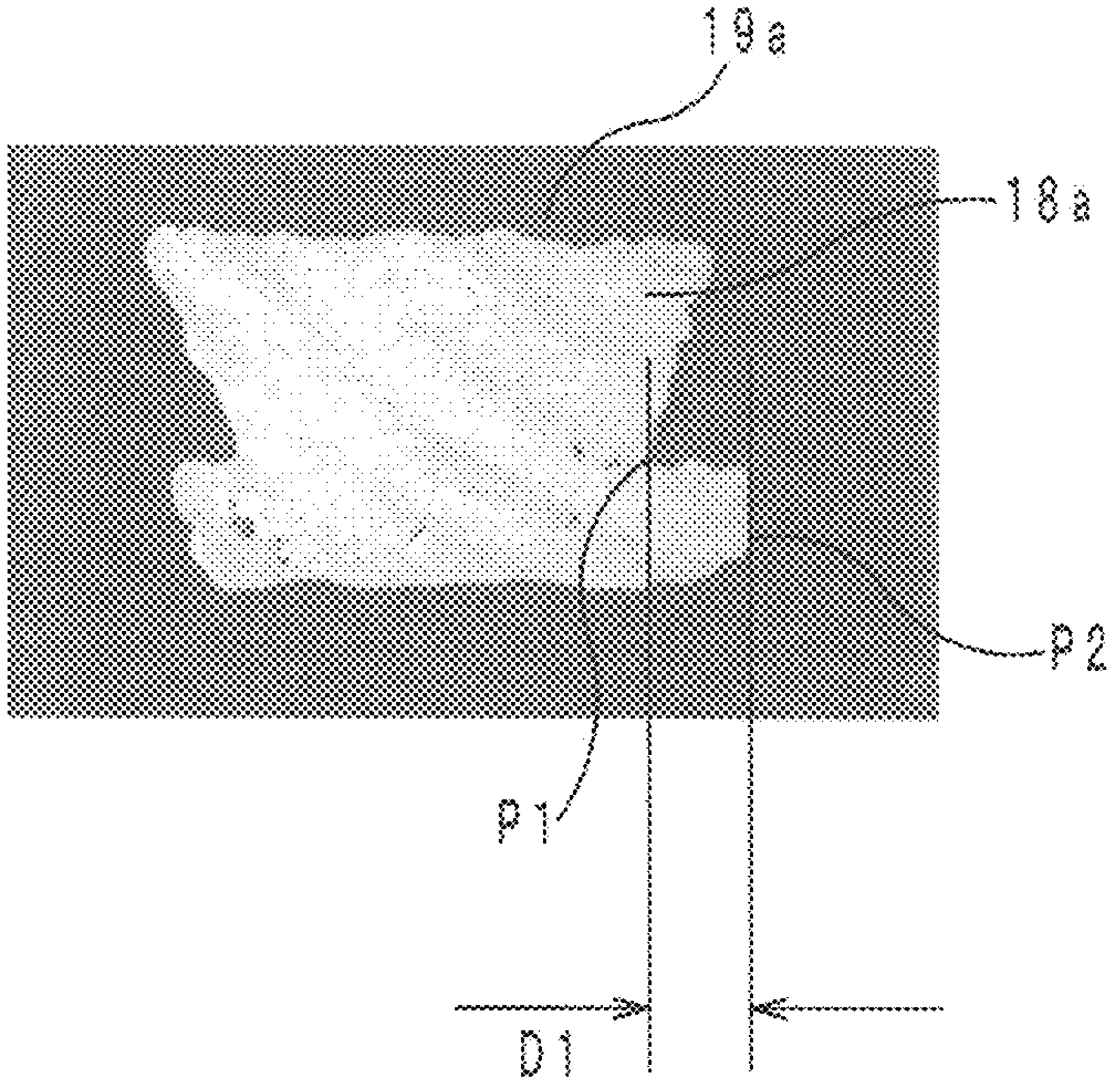

3. 5
3
2. 5
2. 0
1. 5
1. 0
0. 5
RATE OF VARIABILITY (%)
0
10
20
30
DEPTH D1 (μm)
4TH MODEL
5TH MODEL
6TH MODEL
7TH MODEL

FIG. 21



F I G. 22

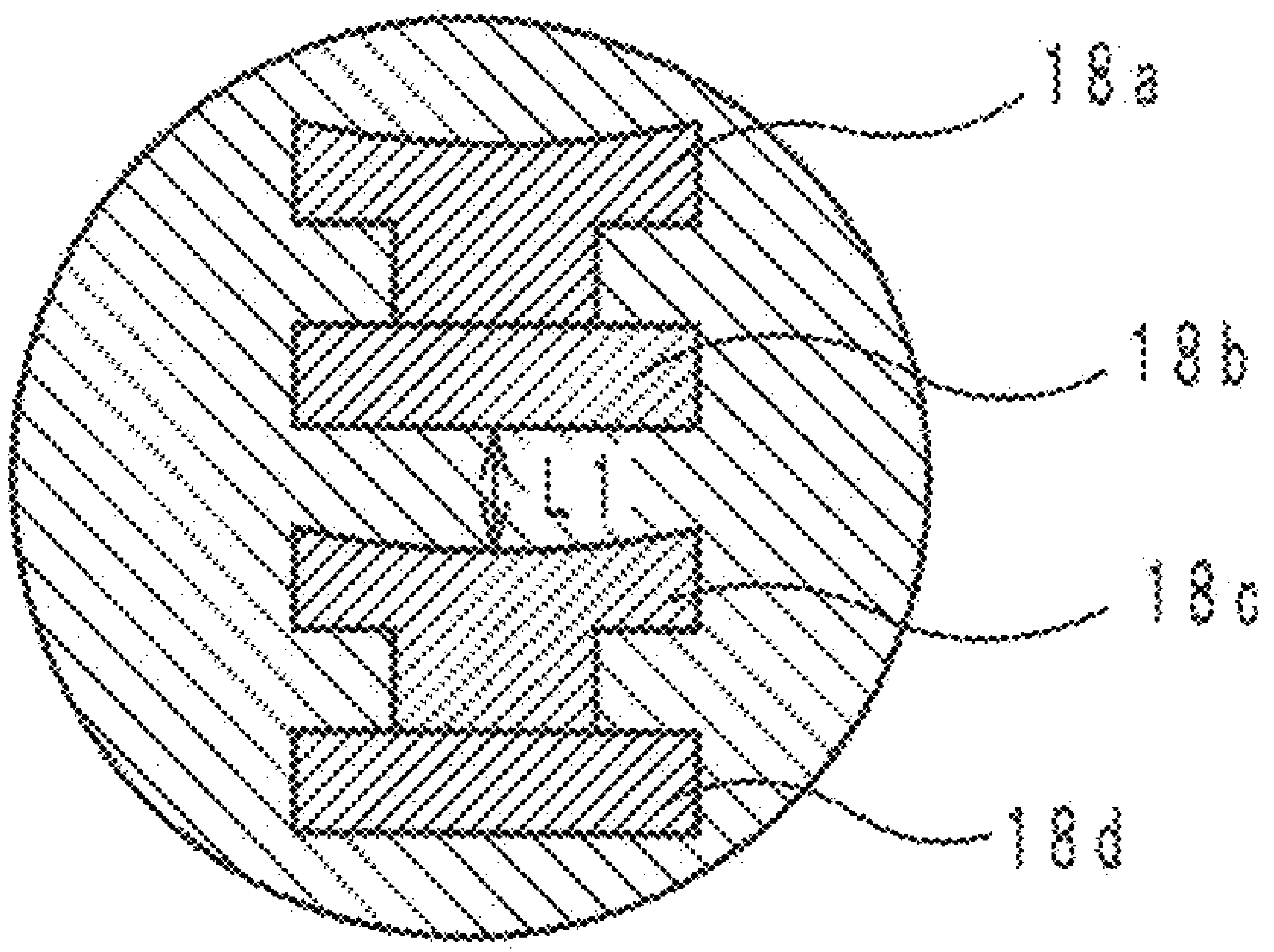
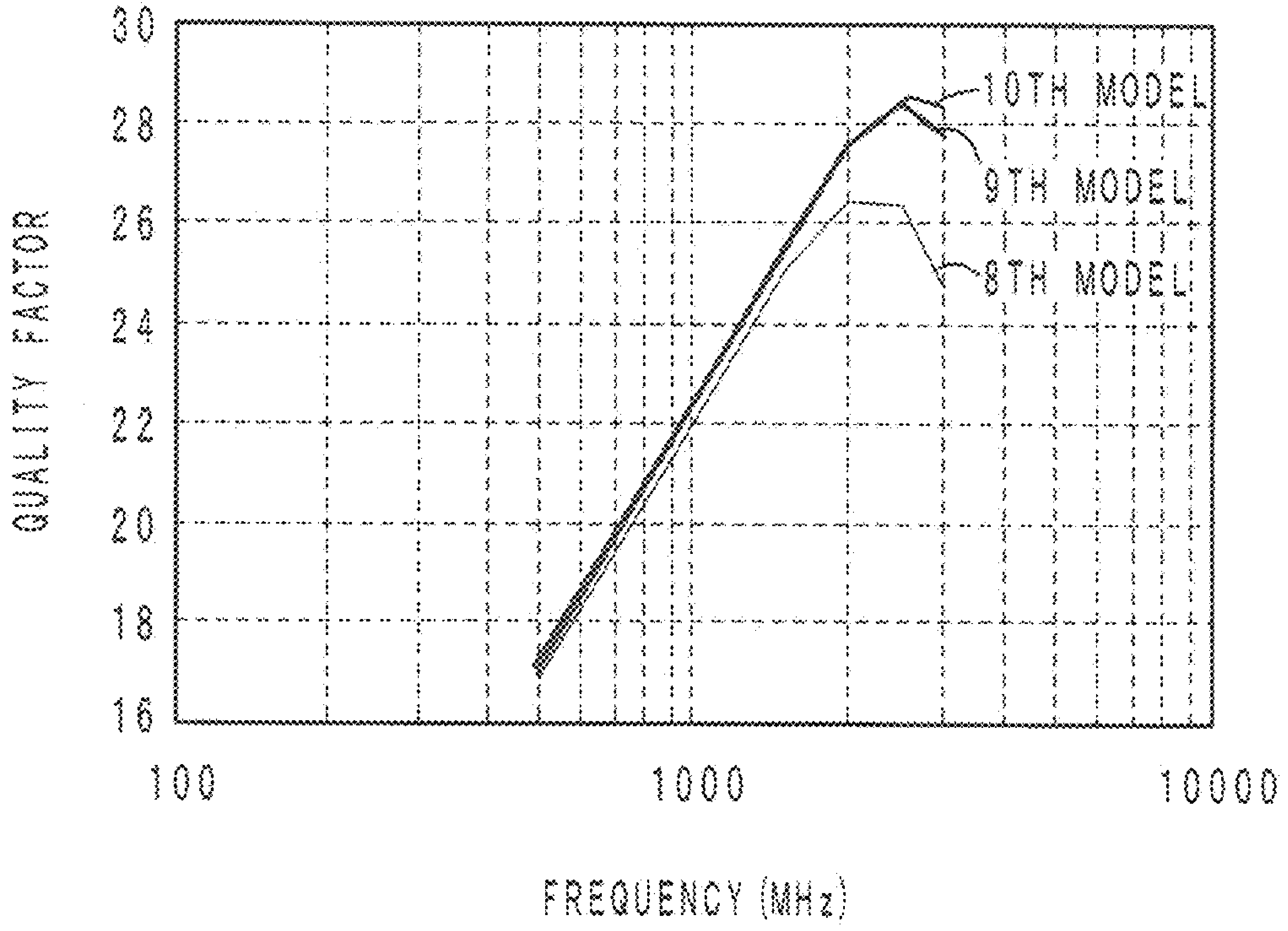


FIG. 23


30
28
26
24
22
20
18
16
QUALITY FACTOR
100
1000
10000
FREQUENCY (MHz)
10TH MODEL
9TH MODEL
8TH MODEL

ELECTRONIC COMPONENT

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims benefit of priority to Japanese Patent Application No. 2013-083048 filed on Apr. 11, 2013, the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

The technical field relates to electronic components, more particularly to an electronic component with an internal coil.

BACKGROUND

As an disclosure relevant to a conventional electronic component, a multilayer electronic component disclosed in, for example, Japanese Patent Laid-Open Publication No. 2000-286125, is known. This multilayer electronic component includes a laminate and a coil. The laminate is formed by laminating a plurality of ferrite sheets. The coil includes a plurality of coil conductor patterns that are connected via through-holes so as to wind helically in the direction of lamination.

Incidentally, to achieve, for example, a low direct-current resistance in the coil, the multilayer electronic component disclosed in Japanese Patent Laid-Open Publication No. 2000-286125 is required to have wider or thicker coil conductor patterns, but in such a case, it is difficult to achieve a large inductance value. More specifically, in the case of a helical coil, the density of magnetic flux in the coil is high. In this case, magnetic flux that does not flow through the coil passes through the surfaces of the coil conductor patterns. Because a high-frequency signal flows through the coil, the direction of magnetic flux generated by the coil varies cyclically. In the case where the direction of magnetic flux that passes through the coil conductor patterns varies cyclically, eddy currents are generated in the coil conductor patterns, so that Joule's heat is produced. As a result, an eddy-current loss occurs, leading to a reduced inductance value of the coil.

SUMMARY

An electronic component according to an embodiment of the present disclosure includes a laminate formed by laminating a plurality of insulator layers, and a coil including linear coil conductor layers laminated along with the insulator layers, the coil having a helical form, which windingly extends in a direction of lamination, or a spiral form. In a cross section perpendicular to a direction in which the coil conductor layers extend, the coil conductor layers have recesses provided in their surfaces directed toward an inner circumference side of the coil, the recesses being set back toward an outer circumference side of the coil.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an external oblique view of an electronic component according to an embodiment.

FIG. **2** is an exploded oblique view of the electronic component in FIG. **1**.

FIG. **3** is a cross-sectional structure view of a laminate of the electronic component taken along line A-A of FIG. **1** and an enlarged area of the laminate.

FIG. **4** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **5** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **6** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **7** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **8** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **9** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **10** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **11** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **12** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **13** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **14** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **15** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **16** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **17** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **18** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **19** is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. **20** is a graph showing simulation results.

FIG. **21** is a photograph showing a cross-sectional structure of a coil conductor layer.

FIG. **22** is a cross-sectional structure view of a coil conductor layer.

FIG. **23** is a graph showing simulation results.

DETAILED DESCRIPTION

Hereinafter, an electronic component according to an embodiment of the present disclosure will be described.

Structure of Electronic Component

The structure of the electronic component according to the embodiment will be described below with reference to the drawings. FIG. **1** is an external oblique view of the electronic component **10** according to the embodiment. FIG. **2** is an exploded oblique view of the electronic component **10** in FIG. **1**. FIG. **3** is a cross-sectional structural view of a laminate **12** of the electronic component **10** taken along line A-A of FIG. **1**. In FIG. **3**, external electrodes **14***a* and **14***b* are not shown. In the following, the direction of lamination of the laminate **12** will be defined as a top-bottom direction. In addition, when the laminate **12** is viewed in a top view, the direction in which the short side of the laminate **12** extends will be defined as a front-back direction, and the direction in which the long side of the laminate **12** extends will be defined as a right-left direction.

As shown in FIGS. **1** through **3**, the electronic component **10** includes the laminate **12**, the external electrodes **14***a* and **14***b*, and a coil L. The laminate **12** is in the form of a rectangular solid formed by laminating insulator layers **25** and **16***a* to **16***i*. The insulator layers **25** and **16***a* to **16***i* are laminated in this order, from top to bottom, and have rectangular edges.

The insulator layer **25** has a blank circle marked thereon. The blank circle is used as a direction marker. Moreover, the insulator layers **16***b*, **16***d*, **16***f*, and **16***h* have respective openings Op**1** to Op**4** provided therein. In addition, the insulator layers **16***c*, **16***e*, and **16***g* have respective through-holes Ta to Tc provided therein. In this manner, the insulator layers **16***b*, **16***d*, **16***f*, and **16***h* with the openings Op**1** to Op**4** and the insulator layers **16***c*, **16***e*, and **16***g* without openings are laminated so as to alternate with each other. The openings Op**1** to Op**4** and the through-holes Ta to Tc will be described later. The insulator layers **16***a* to **16***i* are made from glass containing a magnetic material. Upper and lower surfaces of the insulator layers **16***a* to **16***i* will be referred to below as top and bottom surfaces, respectively.

The coil L spirals clockwise when viewed in a top view, so as to take a helical form continuing from bottom to top. The coil L includes coil conductor layers **19***a* to **19***d* and via-hole conductors Va to Vc. The coil conductor layers **19***a* to **19***d* are linear conductors laminated along with the insulator layers **16***a* to **16***i*, and when viewed in a top view, they wind clockwise around the center of the laminate **12** (the intersection of diagonals). The coil conductor layers **19***a* to **19***d* are made of, for example, a conductive material mainly composed of Ag. In the following, the ends of the coil conductor layers **19***a* to **19***d* that are located upstream in the clockwise direction will be simply referred to as the upstream ends, and the ends of the coil conductor layers **19***a* to **19***d* that are located downstream in the clockwise direction will be simply referred to as the downstream ends.

Furthermore, the coil conductor layer **19***a* includes coil conductor layers **18***a* and **18***b*, as shown in FIG. **2**. The coil conductor layers **18***a* and **18***b* have approximately the same shape when viewed in a top view, and are stacked vertically. More specifically, the coil conductor layer **18***b* is positioned on the top surface of the insulator layer **16***c*. The opening Op**1** is provided in the insulator layer **16***b*, as mentioned earlier. The opening Op**1** has a linear shape which, when viewed in a top view, overlaps with the coil conductor layer **18***b* and is approximately the same as the shape of the coil conductor layer **18***b*. However, the width W**3** of the opening Op**1** is less than both the width W**1** of the coil conductor layer **18***a* and the W**2** of the coil conductor layer **18***b*.

The coil conductor layer **18***a* is provided on the top surface of the insulator layer **16***b* so as to be partially positioned in the opening Op**1**, as shown in FIGS. **2** and **3**. Note that the coil conductor layer **18***a*, when viewed in a top view, reaches beyond the edge of the opening Op**1** on the top surface of the insulator layer **16***b*. Accordingly, in a cross section perpendicular to the direction in which the coil conductor layer **18***a* extends, the coil conductor layer **18***a* is in the shape of a T. Moreover, the lower surface of the coil conductor layer **18***a* contacts the upper surface of the coil conductor layer **18***b*. Accordingly, in a cross section perpendicular to the direction in which the coil conductor layer **19***a* extends, the coil conductor layer **19***a* is in the shape of an H rotated 90 degrees. Therefore, in the cross section perpendicular to the direction in which the coil conductor layer **19***a* extends, the surface of the coil conductor layer **19***a* that is directed toward the inner circumference side of the coil L has a recess Ga set back toward the outer circumference side of the coil L. The depth D**1** of the recess Ga (see FIG. **3**) is preferably 6 μm or more, which is 40% or less of the width W**1** or W**2** of the coil conductor layers **18***a* to **18***h*.

The coil conductor layer **19***b* includes the coil conductor layers **18***c* and **18***d*, as shown in FIG. **2**. The coil conductor layer **19***c* includes the coil conductor layers **18***e* and **18***f*, as shown in FIG. **2**. The coil conductor layer **19***d* includes the coil conductor layers **18***g* and **18***h*, as shown in FIG. **2**. The configurations of the coil conductor layers **19***b* to **19***d* are similar to that of the coil conductor layer **19***a*, and therefore, any descriptions thereof will be omitted. Moreover, the configurations of the openings Op**2** to Op**4** are similar to that of the opening Op**1**, and therefore, any descriptions thereof will be omitted.

The through-holes Ta to Tc are holes that vertically pierce through the insulator layers **16***c*, **16***e*, and **16***g*, respectively. The through-hole Ta, when viewed in a top view, overlaps with both the upstream end of the coil conductor layer **18***b* and the downstream end of the coil conductor layer **18***c*. The through-hole Tb, when viewed in a top view, overlaps with both the upstream end of the coil conductor layer **18***d* and the downstream end of the coil conductor layer **18***e*. The through-hole Tc, when viewed in a top view, overlaps with both the upstream end of the coil conductor layer **18***f* and the downstream end of the coil conductor layer **18***g*.

The via-hole conductor Va projects downward from the upstream end of the coil conductor layer **18***b* so as to be positioned in the through-hole Ta. Accordingly, the via-hole conductor Va connects the upstream end of the coil conductor layer **18***b* to the downstream end of the coil conductor layer **18***c*. The via-hole conductor Vb projects downward from the upstream end of the coil conductor layer **18***d* so as to be positioned in the through-hole Tb. Accordingly, the via-hole conductor Vb connects the upstream end of the coil conductor layer **18***d* to the downstream end of the coil conductor layer **18***e*. The via-hole conductor Vc projects downward from the upstream end of the coil conductor layer **18***f* so as to be positioned in the through-hole Tc. Accordingly, the via-hole conductor Vc connects the upstream end of the coil conductor layer **18***f* to the downstream end of the coil conductor layer **18***g*. Thus, the coil conductor layers **19***a* to **19***d* are connected by the via-hole conductors Va to Vc, thereby forming the helical coil L.

The external electrode **14***a* covers the right end surface of the laminate **12**, and is bent toward the top, bottom, front, and back surfaces of the laminate **12**. The downstream end of the coil conductor layer **19***a* is led out to the right end surface of the laminate **12**. Accordingly, the downstream end of the coil conductor layer **19***a* is connected to the external electrode **14***a*.

The external electrode **14***b* covers the left end surface of the laminate **12**, and is bent toward the top, bottom, front, and back surfaces of the laminate **12**. The upstream end of the coil conductor layer **19***d* is led out to the left end surface of the laminate **12**. Accordingly, the upstream end of the coil conductor layer **19***d* is connected to the external electrode **14***b*.

Method for Producing Electronic Component

Next, the method for producing the electronic component **10** will be described with reference to the drawings. FIGS. **4** through **19** are cross-sectional views corresponding to the steps in the production of the electronic component **10**. While the following description focuses on the process of producing one electronic component **10**, in actuality, a mother laminate is produced and cut, thereby obtaining a plurality of electronic components **10** simultaneously.

Initially, a photosensitive insulator paste is applied by printing, as shown in FIG. **4**. Thereafter, the entire surface of the photosensitive insulator paste is exposed to light, as shown in FIG. **5**. As a result, the photosensitive insulator paste is cured, so that an insulator layer **16***i* is formed.

Next, a photosensitive conductor paste is applied by printing onto the insulator layer **16***i*, as shown in FIG. **6**. Thereafter, the photosensitive conductor paste is exposed to light through a mask M1, as shown in FIG. **7**. The mask M1 has an opening having the same shape as a coil conductor layer **18***h*. As a result, a portion of the photosensitive conductor paste that is to become a coil conductor layer **18***h* is cured. Moreover, the remaining uncured paste is removed by a developer, as shown in FIG. **8**. As a result, a coil conductor layer **18***h* is formed.

Next, a photosensitive insulator paste is applied by printing onto the insulator layer **16***i* and the coil conductor layer **18***h*, as shown in FIG. **9**. Thereafter, the photosensitive conductor paste is exposed to light through a mask M**2**, as shown in FIG. **10**. The mask M**2** covers a portion of the photosensitive insulator paste where an opening Op**4** is to be provided. As a result, the photosensitive conductor paste, other than the portion where an opening Op**4** is to be provided, is cured. Moreover, the remaining uncured paste is removed by a developer, as shown in FIG. **11**. As a result, an insulator layer **16***h* is formed.

Next, a photosensitive insulator paste is applied by printing onto the insulator layer **16***h* and also into the opening Op**4**, as shown in FIG. **12**. Thereafter, the photosensitive conductor paste is exposed to light through a mask M**3**, as shown in FIG. **13**. The mask M**3** has an opening having the same shape as a coil conductor layer **18***g*. As a result, a portion of the photosensitive conductor paste that is to become a coil conductor layer **18***g* is cured. Moreover, the remaining uncured paste is removed by a developer, as shown in FIG. **14**. As a result, a coil conductor layer **18***g* is formed.

Next, a photosensitive insulator paste is applied by printing onto the insulator layer **16***h* and the coil conductor layer **18***g*, as shown in FIG. **15**. Thereafter, the photosensitive conductor paste is exposed to light through an unillustrated mask, as shown in FIG. **16**. The unillustrated mask covers a portion of the photosensitive insulator paste where a through-hole Tc is to be provided. Accordingly, the photosensitive conductor paste, other than the portion where a through-hole Tc is to be provided, is cured. Moreover, the remaining uncured paste is removed by a developer. As a result, an insulator layer **16***g* is formed. Thereafter, the steps of FIGS. **6** through **16** are repeated to form insulator layers **16***b* to **16***f* and coil conductor layers **18***a* to **18***f*, as shown in FIG. **17**.

Next, a photosensitive insulator paste is applied by printing onto the insulator layer **16***b* and the coil conductor layer **18***a*, as shown in FIG. **18**. Thereafter, the entire surface of the photosensitive insulator paste is exposed to light, as shown in FIG. **19**. As a result, the photosensitive insulator paste is cured, so that an insulator layer **16***a* is formed. Further, an insulator paste is applied by printing onto the insulator layer **16***a*, thereby forming an insulator layer **25**. Thus, a mother laminate made up of a plurality of laminates **12** is obtained.

Next, the mother laminate is cut into a plurality of unsintered laminates **12** by a dicing saw or suchlike. In addition, the laminates **12** are sintered under predetermined conditions.

Next, a conductive paste made of Ag is applied to opposite end surfaces of the laminate **12** by dipping, and the end surfaces are baked to form electrode bases. Lastly, the electrode bases are plated with Ni, Cu, Sn, or the like, thereby forming external electrodes **14***a* and **14***b*. By the foregoing process, the electronic component **10** is completed.

Effects

The electronic component **10** according to the present embodiment renders it possible to achieve a large inductance value. More specifically, the helical coil L has a high density of magnetic flux therein. Magnetic flux that does not flow through the coil L passes through the surfaces of the coil conductor layers **18***a* to **18***h*. In this manner, when magnetic flux passes through the coil conductor layers **18***a* to **18***h*, eddy currents are set up, resulting in a reduced inductance value of the coil L.

Here, magnetic flux that does not flow through the coil L passes near the surfaces of the coil conductor layers **19***a* to **19***d* that are directed toward the inner circumference side of the coil L. Accordingly, eddy currents tend to be set up also near the surfaces of the coil conductor layers **19***a* to **19***d* that are directed toward the inner circumference side of the coil L. Therefore, in the electronic component **10**, the surfaces of the coil conductor layers **19***a* to **19***d* that are directed toward the inner circumference side of the coil L have recesses Ga to Gd provided so as to be set back toward the outer circumference side of the coil L. As a result, the coil conductor layers **19***a* to **19***d* are thinner in the top-bottom direction near the surfaces directed toward the inner circumference side of the coil L. Accordingly, the distance that the magnetic flux passes through the coil conductor layers **19***a* to **19***d* becomes shorter. Thus, eddy currents which are set up in the coil conductor layers **19***a* to **19***d* are reduced, so that the inductance value of the coil L can be inhibited from being reduced. Note that the computer simulations to be described below demonstrate that the depth D**1** of the recesses Ga to Gd is preferably 6 μm or more, which is 40% or less of the width W**1** or W**2** of the coil conductor layers **18***a* to **18***h*.

Computer Simulations

To confirm that the foregoing correctly describes the principle of increasing the inductance value of the coil L, the present inventors carried out computer simulations to be described below. The coil conductor layers **19***a* to **19***d* had respective recesses Ge to Gh provided in the surfaces directed toward the outer circumference side of the coil L, as shown in the enlarged view in FIG. **3**. The depth of the recesses Ge to Gh is denoted by D**2**. The inventors calculated inductance values of the coil L with different values of the depths D**1** and D**2**. The details of first through third models used in the computer simulations will be described below.

First Model:
Depth D**1**: 0 μm
Depth D**2**: 0 μm
Second Model:
Depth D**1**: 10 μm
Depth D**2**: 0 μm
Third Model:
Depth D**1**: 0 ∞m
Depth D**2**: 10 μm

For the first model, the inductance value was 2.276 nH. For the second model, the inductance value was 2.321 nH. That is, the inductance value for the second model was higher by 0.045 nH than that for the first model. On the other hand, for the third model, the inductance value was 2.282 nH. That is, the inductance value for the third model is higher only by 0.006 nH than that for the first model. In this manner, it can be appreciated that, in the case where the coil conductor layers **19***a* to **19***d* have the recesses Ga to Gd provided in the surfaces directed toward the inner circumference side of the coil L, the inductance value of the coil L is higher than in the case where the coil conductor layers **19***a* to **19***d* have the recesses Ga to Gd in the surfaces directed toward the outer circumference side of the coil L. Therefore, on the basis of the computer simulations, it is thought that by providing the recesses Ga to Gd, it is rendered possible to reduce eddy currents set up in the coil conductor layers **19***a* to **19***d*, so that the inductance value of the coil L can be inhibited from being reduced.

Next, to find an optimal depth D**1** for the recesses Ga to Gd, fourth through seventh models as detailed below were created, and inductance values for the models were calculated.

Fourth Model:

Width (W**1** or W**2**) of the coil conductor layers **19***a* to **19***d*: 70 μm

Thickness of the coil conductor layers **19***a* to **19***d*: 12 μm

Fifth Model:

Width (W**1** or W**2**) of the coil conductor layers **19***a* to **19***d*: 60 μm

Thickness of the coil conductor layers **19***a* to **19***d*: 12 μm

Sixth Model:

Width (W**1** or W**2**) of the coil conductor layers **19***a* to **19***d*: 40 μm

Thickness of the coil conductor layers **19***a* to **19***d*: 12

Seventh Model:

Width (W**1** or W**2**) of the coil conductor layers **19***a* to **19***d*: 40 μm

Thickness of the coil conductor layers **19***a* to **19***d*: 8 μm

For the fourth through seventh models, inductance values of the coil L were calculated with different values of the depth D**1** of the recesses Ga to Gd. FIG. **20** is a graph showing simulation results. The vertical axis represents the percentage change of the inductance value, and the horizontal axis represents the depth D**1** of the recesses Ga to Gd. The percentage change of the inductance value refers to a percentage change relative to the inductance value where the depth D**1** is 0 μm.

It can be appreciated from FIG. **20** that for all of the fourth through seventh models, the inductance value increased with the depth D**1**. In addition, for all of the fourth through seventh models, the inductance value barely increased where the depth D**1** was 6 μm or more. Therefore, it can be appreciated that the depth D**1** is preferably 6 μm or more. Note that the inventors calculated inductance values with the depth D**1** at 10 μm. Thus, the depth D**1** is preferably 10 μm or less.

Furthermore, for the fourth model, it was found that the inductance value barely changed where the depth D**1** was up to 30 μm. For the fourth model, the width W**1** was 70 μm. Accordingly, for the fourth model, the inductance value barely changed where the depth D**1** was 42.8% or less of the width W**1**. Similarly, for the fifth model, it was found that the inductance value barely changed where the depth D**1** was up to 25 μm. For the fifth model, the width W**1** was 60 μm. Accordingly, for the fifth model, the inductance value barely changed where the depth D**1** was 42.5% or less of the width W**1**. For the sixth model, it was found that the inductance value barely changed where the depth D**1** was up to 16 μm. For the sixth model, the width W**1** was 40 μm. Accordingly, for the sixth model, the inductance value barely changed where the depth D**1** was 40.0% or less of the width W**1**. For the seventh model, it was known that the inductance value barely changed where the depth D**1** was up to 16 μm. For the seventh model, the width W**1** was 40 μm. Accordingly, for the seventh model, the inductance value barely changed where the depth D**1** was 40.0% or less of the width W**1**. Thus, the depth D**1** of the recesses Ga to Gd is preferably 40% or less of the width W**1** or W**2** of the coil conductor layers **18***a* to **18***h*.

Other dimensions of the coil conductor layers **19***a* to **19***d* will also be described. It is preferable that the portions of the coil conductor layers **18***a*, **18***c*, **18***e*, and **18***g* that are positioned on the insulator layers **16***b*, **16***d*, **16***f*, and **16***h*, respectively, as shown in FIG. **3**, have a thickness H**1** of from 8 μm to 12 μm. Moreover, it is preferable that the portions of the coil conductor layers **18***a*, **18***c*, **18***e*, and **18***g* that are positioned in the openings Op**1** to Op**4**, respectively, have a thickness H**3** of 7 μm. In addition, the coil conductor layers **18***b*, **18***d*, **18***f*, and **18***h* preferably have a thickness H**2** of from 8 μm to 12 μm.

Method for Measuring Recess Depth

The method for measuring the depth D**1** of the recesses Ga to Gd will be described below with reference to the drawings.

Initially, curable resin is applied to the electronic component **10** and hardened. The electronic component **10** with the hardened resin is ground to expose a cross section of the coil conductor layer **19***a*. Further, the exposed cross section of the coil conductor layer **19***a* is buffed to eliminate grounding flaws therefrom. Thereafter, an image of the cross section of the coil conductor layer **19***a* is taken by a laser microscope (VK-8700 from Keyence Corp.). FIG. **21** is a photograph showing the cross-sectional structure of the coil conductor layer **19***a*.

In actuality, the cross-sectional shape of the coil conductor layer **19***a* is significantly different from the shape of an H, as shown in FIG. **21**. Therefore, in the case where the depth D**1** of any of the recesses Ga to Gd is measured, the bottom of that recess is determined first. For example, in the case of the recess Ga, its bottom, which is denoted by P**1** in FIG. **21**, is the closest portion to the outer circumference side of the coil L. Next, the entrance of the recesses Ga to Gd is determined. For example, in the case of the recess Ga, its entrance, which is denoted by P**2**, corresponds to the closest portion of the coil conductor layer **19***a* to the inner circumference side of the coil L, as shown in FIG. **21**. Thereafter, the distance between the portions P**1** and P**2** in the right-left direction is measured and set as a depth D**1**. By the above process, the depth D**1** can be measured.

Modification

Hereinafter, an electronic component **10***a* according to a modification will be described with reference to the drawings. FIG. **22** is a cross-sectional structure view of the coil conductor layer **19***a*. For the external oblique view and the exploded oblique view of the electronic component **10***a*, FIGS. **1** and **2** will be referenced.

The electronic component **10***a* differs from the electronic component **10** in terms of the cross-sectional shape of the coil conductor layers **19***a* to **19***d*. In the following, the cross-sectional shape of the coil conductor layers **19***a* to **19***d* will be described, but any descriptions of other features will be omitted.

The surface of the coil conductor layer **18***c* that is opposite to the coil conductor layer **18***b* with the insulator layer **16**c positioned therebetween, i.e., the upper surface of the coil conductor layer **18***c*, is concave. Accordingly, the distance between the coil conductor layers **18***b* and **18***c* is increased. As a result, an increase in insertion loss in the electronic component **10***a* due to proximity effect is inhibited. While the foregoing has been given by taking as an example the relationship between the coil conductor layers **18***b* and **18***c*, the same can be said of the relationship between the coil conductor layers **18***d* and **18***e* and also of the relationship between the coil conductor layers **18***f* and **18***g*.

To clearly demonstrate that the insertion loss in the electronic component **10***a* is suppressed, the inventors carried out computer simulations to be described below. Specifically, the inventors created eighth through tenth models as will be detailed below, and studied the relationship of the frequency of a high-frequency signal with a quality factor.

The specifications common among the eighth through tenth models are as follows:

Width (W**1** or W**2**) of each coil conductor layer: 65 μm

Number of coil conductor layers: 5

Number of winds of the coil L: 4.5

Distance from the coil L to the end surface of the laminate: 23 μm

The distance L**1** between the coil conductor layers **18***b* and **18***c* is shown below for each model:

Eighth model: 5 μm

Ninth model: 10 μm

Tenth model: 15 μm

FIG. **23** is a graph showing simulation results. The vertical axis represents the quality factor, and the horizontal axis represents the frequency. It can be appreciated from FIG. **23** that the quality factor peaks at a higher level as the distance L**1** increases. Specifically, it can be appreciated that an increase in the distance L**1** between the coil conductor layers **18***b* and **18***c* due to the upper surface of the coil conductor layer **18***c* being concave results in an increase in the quality factor in the electronic component **10***a*. Thus, it can be appreciated that the insertion loss in the electronic component **10***a* can be suppressed by increasing the distance L**1**.

Furthermore, it can be appreciated from FIG. **23** that the peak quality factor was significantly improved when the distance L**1** was 10 μm or more. Thus, the distance L**1** is preferably 10 μm or more.

Other Embodiments

The present disclosure is not limited to the electronic components **10** and **10***a*, and variations can be made within the spirit and scope of the disclosure.

Note that the electronic components **10** and **10***a* are provided with the recesses Ge to Gh, but the recesses Ge to Gh are not indispensable.

Furthermore, in the case of the electronic components **10** and **10***a*, the coils L are helical coils, but they may be any coils that are in the form of, for example, spirals when viewed in a top view. Moreover, the coils L may be helical coils formed by connecting a plurality of spiral coil conductor layers.

Although the present disclosure has been described in connection with the preferred embodiment above, it is to be noted that various changes and modifications are possible to those who are skilled in the art. Such changes and modifications are to be understood as being within the scope of the disclosure.

What is claimed is:

1. An electronic component comprising:

a laminate formed by laminating a plurality of insulator layers;

a coil including linear coil conductor layers laminated along with the insulator layers, the coil having a spiral form; and

via-hole conductors extending through the insulator layers and connecting the coil conductor layers, wherein,

in a cross section perpendicular to a direction in which the coil conductor layers extend, the coil conductor layers have recesses provided in surfaces directed toward an inner circumference side of the coil, the recesses being set back toward an outer circumference side of the coil,

the recesses are positioned in portions of the coil conductor layers a spaced distance from the via-hole conductors along the direction in which the coil conductor layers extend, and

the recesses have a depth of greater than or equal to 6 μm and less than 20 μm.

2. The electronic component according to claim **1**, wherein a depth of the recesses is 40% or less of the width of a coil conductor layers.

3. The electronic component according to claim **1**, wherein,

the insulator layers include first insulator layers and second insulator layers laminated thereon,

the coil conductor layers include first and second coil conductor layers,

the first coil conductor layers are provided on the first insulator layers,

the second insulator layers have linear openings narrower than the first and second coil conductor layers, the openings overlapping with the first coil conductor layers when viewed in a plan view in a direction of lamination, and

the second coil conductor layers are provided on the second insulator layers so as to be partially positioned in the openings.

4. The electronic component according to claim **1**, wherein the recesses have a depth of greater than or equal to 6 μm and less than or equal to 16 μm.

5. An electronic component comprising:

a laminate formed by laminating a plurality of insulator layers;

a coil including linear coil conductor layers laminated along with the insulator layers, the coil having a helical form which windingly extends in a direction of lamination; and

via-hole conductors extending through the insulator layers and connecting the coil conductor layers, wherein,

in a cross section perpendicular to a direction in which the coil conductor layers extend, the coil conductor layers have recesses provided in surfaces directed toward an inner circumference side of the coil, the recesses being set back toward an outer circumference side of the coil,

the recesses are positioned in portions of the coil conductor layers a spaced distance from the via-hole conductors along the direction in which the coil conductor layers extend, and

the recesses have a depth of greater than or equal to 6 μm and less than 20 μm.

6. The electronic component according to claim **5**, wherein a depth of the recesses is 40% or less of the width of the coil conductor layers.

7. The electronic component according to claim **5**, wherein,

the insulator layers include first insulator layers and second insulator layers laminated thereon,

the coil conductor layers include first and second coil conductor layers,

the first coil conductor layers are provided on the first insulator layers,

the second insulator layers have linear openings narrower than the first and second coil conductor layers, the openings overlapping with the first coil conductor layers when viewed in a plan view in a direction of lamination, and

the second coil conductor layers are provided on the second insulator layers so as to be partially positioned in the openings.

8. The electronic component according to claim **7**, wherein,

the first insulator layers and the second insulator layers are laminated so as to alternate with each other,

the coil is a helical coil formed by connecting the coil conductor layers each including the first and second coil conductor layers, and

the second coil conductor layers have concave surfaces each being opposite to the first coil conductor layer with the first insulator layer positioned therebetween.

9. The electronic component according to claim **5**, wherein the recesses have a depth of greater than or equal to 6 μm and less than or equal to 16 μm.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	: 9,362,042 B2	Page 1 of 1
APPLICATION NO.	: 14/203497	
DATED	: June 7, 2016	
INVENTOR(S)	: Masayuki Yoneda et al.	

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Specification

In column 6, line 50, replace “Depth D1: 0 oom” with “Depth D1: 0 µm”;

In column 7, line 17, replace “Thickness of the coil conductor layers 19a to 19d: 12” with “Thickness of the coil conductor layers 19a to 19d: 12 µm”.

Signed and Sealed this
Sixth Day of September, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office